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POUR L'EXPLORATION DE LA MER

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E. S. RUSSELL

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IMPRIMERIE BIANCO LUNO

# A quantitative consideration of some factors concerned in plant growth in water

by

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Since plant growth is dependent upon an adequate supply of radiant energy for use in the endothermic processes of photosynthesis it is necessary first of all to consider what is the intensity of the light at the surface and at various depths in the sea and in fresh waters. As photosynthesis depends upon the wave-length of the light available attention must also be paid to this. From such a survey we may arrive at a more correct understanding of the possibilities of the ocean and of fresh water lakes as habitations for plants. The fields of the waters have both area and depth, and it is the depth accessible to adequate illumination that enables them to support such an abundant flora. As on the land, the fauna are ultimately dependent upon the flora for their food supply, so a consideration of the conditions of plant growth is of fundamental importance.

Having formed an idea of the energy available it is necessary to consider how far this can be turned to account by the plants, inasmuch as they require for their growth many inorganic compounds, including at least nine elements. A deficiency either of energy or of a necessary constituent leads to a cessation of growth.

It is the object of this paper to summarise some of the results obtained in recent years upon these questions so that they may be the more readily assimilated by biologists in general.

References have been given for portions of the subject which could not be considered in any detail.

## PART I.[1]) SOME PHYSICAL FACTORS

### Submarine illumination and algal distribution.

Qualitative tests with photographic plates have shown that light may be detected at great depths, but as far as plant growth is concerned

[1]) Part II will appear in a subsequent number of the Journal.

such records afford little information. Continued existence only becomes possible for plants when the light is of such an intensity that it enables photosynthesis to be carried out at a rate at least equal to that at which the carbon compounds of the plants are dissipated through respiration. It might be thought possible to determine this limiting depth, variable of course from season to season and from one latitude to another, by noting the distribution of the algal belts which surround our coasts. This method certainly does afford much information and the algal belts, supplemented in certain localities by the phanerogams *Zostera*, *Posidonia* etc., are an important source of food supply for marine animals in shallow waters.

It is of interest therefore to consider the distribution of these sea plants. As is well known they are arranged along the coasts in zones. Green algae abound in brackish waters at the landward side of the strip between high and low water-mark. On the sea coasts, if present at all, it is usually where a trickle of water flows out from the land, for unlike the brown and red algae certain green algae can endure large and rapid fluctuations in salinity.

Green algae are often found in rock-pools, where sometimes brown and red algae also flourish side by side.

Brown algae however constitute the main mass of the inter-tidal vegetation. Around these shores the species found at the highest level on the rocks is *Pelvetia canaliculata*, followed by *Fucus*, especially *F. serratus* around Plymouth Sound and the adjacent coasts. The great masses of *Ascophyllum bulbosum*, so common in estuaries, disappear on the open coasts, save in sheltered spots, since apparently this species cannot endure the strong buffeting of waves. Around the level of low water spring tides the principal genus is *Laminaria*, the most massive of the British algae.

Gradually however the brown algae merge with, and are replaced by, the red. Even among the upper zones of the brown algae the red alga *Porphyra* is found and species of the smaller epiphytic algae, such as *Polysiphonia fastigiata* upon *Ascophyllum*. A detailed consideration of algal zoning is foreign to the intention of this paper, much information upon it may be found in papers by Falkenberg (1878), Boergesen (1903, 1908), Cotton (1915), also by Johnson and York (1915).

The distance to which the various classes of algae extend is dependent very markedly upon the latitude. On the Egyptian coast the narrow inter-tidal zone is devoid of algal life, owing to the scorching heat, whereas around the British Isles this zone is one of luxuriant vegetation. Indeed on the exposed coasts of the Faroe Is. algae extend in places for more

than 100 feet from the highest water mark. The depth to which they penetrate varies also with latitude, owing to the lower altitude of the sun and probably also to the greater amount of sediment retained in suspension by the water of the rougher northern seas. Thus BOERGESEN considers that in such waters only a sparse vegetation is found below 36 metres.

HAMEL (1923) records that in the English Channel the "Pourquoi Pas?" dredgings brought up nothing but species of *Melobesia* from depths greater than 35 m., the latter however persisted down to 45 m. WALTHER (1893) cites the finding of a fairly abundant flora of red algae at 130 m. in the Mediterranean at Capri. Indeed off the Egyptian coast large quantities of even the phanerogam *Posidonia oceanica* flourish among the sponge beds and down to 20, 25 and even 35 m. (OSTENFELD 1918), and appear indirectly to constitute the food supply of the latter. It is of interest to note that under these conditions the Secchi disc was visible to about 35 m. also. As shown by POOLE and ATKINS (1926) the light is then about $^1/_3$ of that in air at the surface.

In fresh waters the shallow marginal areas are characterised by a vegetation in which as a rule phanerogams and primitive vascular cryptogams are dominant rather than algae. Interesting data are given by PEARSALL (1920, 1921). In Alpine lakes PASCHER (1923) records that *Chlorophyceae* decrease among the shore algae till in the zone from 7—12 metres they are replaced by diatoms and blue green algae, with flagellates. Red forms become more numerous and increase in colour from red spotted olive green to deep red finally. Reddish to red *Cyanophyceae* of all families are found.

### Experimental studies on algal distribution.

It has been tacitly assumed in the foregoing that light, whatever its intensity, is beneficial to algae, but their zoning and the following experimental work indicates that the amount and spectral character of the light must also be considered.

It was found (1922) that when *Ceramium* sp. epiphytic, on *Fucus serratus*, was exposed to sea water rendered alkaline by the active photosynthesis of *Ulva latissima* an immersion of two and a half hours at 27° sufficed to render its cells permeable and to kill the plant. The *Ceramium* was entirely surrounded by the thallus of *Ulva*, so that it received no direct sunlight and the water increased in alkalinity from pH 8.2 to 9.4, namely more than tenfold. Obviously a much smaller increase would

have an injurious effect upon the red alga, so that in pools and shallow water *Ulva* might be regarded as a highly undesirable neighbour.

Gail (1918, 1919) has shown that *Fucus evanescens* never grows in tide pools or where *Ulva* is found in any considerable quantity, and also that the growth of the young plants is very much inhibited in sea water at pH 8.4, and almost completely ceases at pH 8.6. The writer has found rock pools as alkaline as pH 8.6 and fresh water ponds in places may be up to pH 9.6.

Furthermore Moore, Whitley and Webster (1922) have recorded that while the green alga *Enteromorpha compressa* carries on photosynthesis about seven times as actively in sunlight as in diffuse light and the brown algae *Fucus serratus* and *Laminaria digitata* behave similarly, yet *Desmarestia aculeata* is about as active in the diffuse as in sunlight, and the same is true for the average results with the red algae *Plocamium coccineum*, *Polysiphonia elongata*, *Delesseria sanguinea* and *Rhodymenia palmata*.

The work of Gail (1922) constitutes the most complete study of this problem. He showed that with a clear sky and smooth water the maximum amount of photosynthesis carried on by various red algae is at a depth of 15 metres, though if the same species collected from shallower water are tried it is found that the most favourable depth is much less. This he attributes to the lesser amount of red pigment in the shallow water members of the several species.

*Fucus evanescens* and *Nereocystis luetkiana* photosynthesise most actively at one metre, but eight metres depth is best for *Costaria costata* and *Laminaria* sp. which grow below low water mark. *Desmarestia ligulata* is most active at about 15 m., thus it — and *D. aculeata*, studied by Moore, — resemble the red algae, which is quite in keeping with the finding of *D. aculeata* down to 27 m. by Boergesen. Choppy water or cloudy weather may raise the optimum depths considerably. In Puget Sound, where Gail worked, 35 m. is about the lower limit at which photosynthesis takes place in both red and brown algae.

It may be added that, in the course of his work on the growth of the sporelings of *F. evanescens* on shells suspended at various depths, Gail found that no diatoms grew on the shells below 6 m.

It is evident from the foregoing that at a depth of 5 metres there is a diminution in the light, which becomes far more marked at 10 m., and at 15—20 m. the number of algal forms able to endure has been greatly diminished, in northerly latitudes at any rate.

In the open sea however we meet with diatoms and peridinians, microscopic and free floating. For these we can only infer the depth at

which limiting or equilibrium photosynthesis is possible. It may perhaps be taken as not far from that which the lowest brown algae endure. The latter are however exposed to tidal variations amounting to an alteration of 0—10 metres (according to geographical position) in their effective depth, such changes constituting a large percentage of the total. The fact that diatoms etc. are met with at 50 or 100 metres is no proof that they are within the necessary limit of illumination as they may be slowly sinking or owe their position to vertical mixing of the water.

Another point of importance in this connection is that far from land the water is, on an average, clearer than near the shore. Thus it results that very different depths may receive an equal percentage of the illumination on a horizontal surface above the water. The condition of the surface of the water is also of importance.

### Measurements of submarine illumination.

Quantitative measurements of submarine illumination were made by REGNARD (1891) using a selenium cell the resistance of which alters when light falls on it. The cell was connected by a long cable to a galvanometer in the Monaco laboratory, the apparatus being lowered from a boat. The following are the results obtained as quoted from REGNARD's book or read off from his graph. The air observation was made in full sunlight. As pointed out by SHELFORD and GAIL the lower values indicate a transmission greater than that for pure water. REGNARD's figures denote galvanometer scale readings, from which two other columns have been calculated, one the percentages of the air value, the other those of the one metre value. REGNARD obtained another set of results by noting the volumes of hydrogen and chlorine which had united in long horizontal tubes, at various depths, under the influence of light. The readings scaled off from his graph are given below, but there is a doubt as to the actual depth owing to the ambiguous position of the figures indicating depth, which are printed — and have been taken as reading — half way between the vertical rulings; this interpretation is borne out by the picture, not to scale, of the apparatus.

REGNARD remarks that the curves obtained by plotting his readings given by the two methods are sensibly the same, but in making this statement appears to have overlooked the fact that the first point on one was an air reading, the first in the other a water reading. His book contains a most interesting account of the earlier qualitative work on light penetration, and the experiments he carried out on the duration of the day, as measured by the darkening of sensitised paper, at various

Table 1. Regnard's submarine illumination data.

| Selenium cell results | | | | Recombination of hydrogen and chlorine | | | %[1] |
|---|---|---|---|---|---|---|---|
| m | Galv. deflect. | % | % | m | c. c. used up, % | % | |
| Air, 0 .. | 260 | 100 | — | — | — | — | — |
| 1 .. | 135 | 52 | 100 | 1.5 | 79 | 100 | 100 |
| 2 .. | 104 | 40 | 77 | — | — | — | — |
| 3 .. | 95 | 36.5 | 70 | — | — | — | — |
| 4 .. | 89 | 34 | 65.5 | 3.7 | 25 | 32 | 48 |
| 5 .. | 84 | 32 | 61.5 | — | — | — | — |
| 6 .. | 82 | 31.5 | 60.5 | 5.7 | 12.5 | 16 | 29 |
| 7 .. | 80 | 31 | 60 | — | — | — | — |
| 8 .. | 79 | 30.5 | 59 | 8.1 | 10 | 13 | 22 |
| 9 .. | 78 | 30 | 58 | — | — | — | — |
| 10 .. | 77 | 29.5 | 57 | 10.3 | 9 | 11 | 15 |
| Shade .. | 66 | 25.5 | 50 | — | — | — | — |
| No light. | 0 | 0 | 0 | — | 0 | 0 | — |

[1]) This column has been calculated from the average percentage results of SHELFORD and GAIL, which as will be explained later are a record mainly of the chemically active blue rays. The agreement is tolerably good in view of the fact that the water off Monaco, 50 metres deep, was probably less clear than that of Puget Sound, over 200 metres in depth. These calculated results are worked out for the nearest metre.

depths are of value. Working at Funchal, Madeira on March 27th—29th he found that whereas above water the day lasted $10^1/_2$ hours, at 20 m. it only lasted 7, sunshine — shown by intense darkening — lasted at this depth $1^1/_2$ hours instead of three. At 30 m. the day was 5 hours with 10 minutes sunshine, whereas in air it was 12 hours with 8 hours sunshine. At 40 m. there was only one hour of feeble light. These results have an important bearing on the problem of the rapidity of the spring increase in phytoplankton in our northerly latitudes. There are however many reasons for thinking that the vernal outburst is a surface — 5-10 metre — layer phenomenon at its onset.

REGNARD's quantitative results have been given at lenth partly for their intrinsic and historic interest, partly because the supposed diminution of light intensity in passing from air to one metre depth has been much quoted and the anomalous results given by the selenium cell need to be pointed out. This cell gives readings which are affected by duration of exposure and changes in temperature, the latter also affect its sensitivity to light from different parts of the spectrum in a dissimilar manner.

KNUDSEN (1922) devised a special spectro-photometer consisting of

two identical optical arrangements, hung on the same line, one above the other, so that the water-layer whose absorption coefficients are to be measured lies between the two. The method measures only light making a small angle with the vertical. This is of interest in comparing his absorption coefficients with those of SHELFORD and GAIL, also POOLE and ATKINS, whose methods take in the more oblique light which should be more rapidly absorbed for a given vertical depth.

If the water-layer is of thickness $x$, and if $I_0$ indicates the illumination on a horizontal surface at the upper end of the column and I that at the lower, then:— $I = I_0 e^{-\mu x}$, where $e$ represents the base of the natural logarithms, $e = 2.71828$ and $\mu$ is a value defined by the above equation and termed the coefficient of absorption. This coefficient is that for the water together with the plankton organisms and inorganic matter in suspension, its variation is therefore an indication of the quantity of suspended matter.

KNUDSEN worked in Nyborg Fjord on the 11th of June, 1921 in water 9 m. deep, temperature 14.5° at all depths, salinity 17.0 ‰ at the surface and 18.5 ‰ at 8 m. depth. This indicates an absence of vertical mixing. Plankton was abundant. The depth visibility limit was 4 metres, no mention is made of what was used to test visibility, presumably it was the apparatus. In the following table his results are shown, the values of $\mu$ being in reciprocal metres, for various standard wave lengths, $\lambda$, expressed in Ångström units (viz. $1 \times 10^{-10}$ metre).

Table 2.

| Depth interval, metres | Values of $\mu$ | | | | | |
|---|---|---|---|---|---|---|
| | $\lambda = 6500$ Red | 6000 Orange red | 5500 Yellow green | 5000 Blue green | 4500 Blue | 4000 Violet |
| 1—3..... | 0.38 | 0.30 | 0.19 | 0.16 | 0.30 | 0.58 |
| 3—5..... | 0.38 | 0.28 | 0.20 | 0.21 | 0.27 | 0.40 |
| 5—7..... | 0.60 | 0.49 | 0.38 | 0.27 | 0.39 | 0.64 |
| 1—8..... | — | 0.275 | 0.181 | 0.184 | 0.300 | — |

The coefficient of absorption has a pronounced minimum for $\lambda = 5100$, namely in the green portion of the spectrum. From this point the coefficients increase both towards the red and the violet, the absorption being high in the latter especially.

The high absorption in the 5—7 metres interval is attributed to a clouding of the water owing to anchoring, the effect passing away before the 1—8 metre water was examined.

From the equation previously given it is possible to calculate the depth at which the light is the one thousandth part of that directly below the surface (termed for short the sub-surface light) and how many times weaker the illumination becomes at a depth of 10 m., as compared with that just below the surface. In these equations use is made of the values obtained for $\mu$ at various values of $\lambda$. The values thus obtained are tabulated as follows: —

Table 3.

| | Red | Orange red | Yellow green | Blue green | Blue | Violet |
|---|---|---|---|---|---|---|
| $\lambda$ (Ångström units) ..... | 6500 | 6000 | 5500 | 5000 | 4500 | 4000 |
| $\mu$ (1/metres)..... | 0.38 | 0.275 | 0.181 | 0.184 | 0.300 | 0.50 |
| $x = d$ for 0.001 of sub-surface light..... | 18 | 25 | 38 | 37 | 23 | 14 |
| Fraction of sub-surface light when $d = 10$ m. ..... | 1/45 | 1/16 | 1/7 | 1/7 | 1/20 | 1/148 |
| Percentage of sub-surface light when $d = 10$ m.... | 2.2 | 6.2 | 14.3 | 14.3 | 5.0 | 0.67 |

From these figures it may be seen that at 10 metres, in the water studied by KNUDSEN, the light contained only about one seventh as much red as compared with the yellow and blue greens, judged by the proportions of each found in normal daylight. The blue was similarly reduced to nearly one third and the violet to one twentieth. The predominant colour of the light in this water was accordingly greenish. Since however inshore waters look far greener than does the open sea it appears probable that really blue sea water, relatively free from suspended matter, permits of the passage of a larger proportion of blue light. This is confirmed by the observations of FOL, who used a diving dress and descended to 30 m. in the Mediterranean. He comments on the variation in tint of the water, viewed in a horizontal direction, which changes from greyish green to a greenish blue according as off shore or deep water currents prevail; the veer towards blue became much more marked the further down he went. At 25 to 30 m. dark red animals appeared black, and green or blue green algae appeared lighter in comparison. On ascending quickly he found that his eyes, accustomed to this blue light, saw his aerial surroundings tinted red.

The observations of VOGEL also support the view that in pure sea water the absorption of light is least in the blue. In the island of Capri, in the Bay of Naples is a celebrated grotto, entered at low water only

No direct daylight penetrates there, its light has all passed through the water; in its course it has been deprived of red, orange, a portion of its green and of violet as shown by spectroscopic examination, so that it then appears a magnificent blue.

Similar qualitative results were obtained by Oltmanns (1891) who examined spectroscopically the light transmitted through tubes, filled with North Sea water, up to 17.2 m. in length. He found that in traversing this distance the red end of the spectrum had been absorbed down to 5900 Å, and weakened to 5180 Å; also the blue up to 4500 Å had been absorbed.

Klugh (1925) devised another photometer in which panchromatic photographic plates are exposed beneath a set of neutral (non-selective) percentage transmission filters, the plates exposed to the lower intensities being read against the plate exposed to the highest intensity, so that the results are given directly in percentages. In order to obtain information concerning the spectral quality of the light Wratten filters for red, green and blue were used. Klugh's provisional results are quoted in the Table 4, and, so far as sea-water is concerned, they do not distinguish between the penetration of different parts of the spectrum. A second column has been interpolated, giving the submarine values as

Table 4. Light penetration into water. Bright sun, clear sky; surface of water smooth.

| Depth in metres | Klugh's panchromatic plate results, Bay of Fundy at St. Andrews, New Brunswick, Aug. 3rd. 1924. | | Shelford and Gail's results, with photo-electric cell mainly blue sensitive, Puget Sound, Aug. 1921. Average of sixteen sets. | |
|---|---|---|---|---|
| | % | % | % | % |
| Air | 100 | 130 | 100 | 132 |
| 0.02 | 77 | 100 | 75.7 | 100 |
| 0.25 | 73 | 95 | — | — |
| 0.5 | 69 | 90 | — | — |
| 1 | 50 | 65 | 62.4 | 82.2 |
| 2 | 21 | 27 | 45.7 | 69.6 |
| 3 | 9 | 12 | 36.3 | 48.9 |
| 4 | 7 | 9 | 30.0 | 39.5 |
| 5 | 3.8 | 5 | 23.0 | 30.3 |
| 6 | — | — | 18.7 | 24.5 |
| 7 | — | — | 16.1 | 21.3 |
| 8 | — | — | 13.7 | 18.1 |
| 9 | — | — | 11.4 | 15.0 |
| 10 | 1.1 | 1.5 | 9.5 | 12.6 |

percentages of the value in air, using KLUGH's value, 77 per cent for the 2 cm. reading, as a basis.

The two methods, the second of which will be discussed later, give concordant results for the surface loss but the values vary widely according to conditions. The deeper the penetration the worse is the agreement since the Puget Sound water was by far the clearer; also the methods are measuring different amounts of the total spectrum and the selective absorption of the water naturally leads to a discrepancy. KLUGH's paper contains a critical account of the work on light penetration into water and woods, with a valuable bibliography of 126 titles.

SHELFORD and GAIL (1922) made a notable advance by introducing the KUNZ photo-electric cell, a potassium hydride cell filled with argon under low pressure, for the measurement of submarine illumination. By means of it they studied light penetration to a depth of 200 metres in Puget Sound. For their numerous results and the application to the study of algal distribution the original paper should be consulted, but a selection is quoted hereafter.

It should be mentioned that the KUNZ cell has its maximum sensitivity at about 4400 Å, namely in the blue, by 4000 (extreme violet) it has fallen to 40 % of the maximum, which value is reached at 4900 — the blue green — on the other side. By 5600 — the yellowish green — a decrease to 3 % has been experienced (SHINOMIYA, 1919). These values are plotted in Fig. 1, copied from SHELFORD and GAIL, along with other data as shown in the legend. It may be seen that, as long as we are concerned with white light only, the cell will register changes in illumination which accord with visual estimates (neglecting the adaption of the eye to intensity — which is very great in its range). When however we are concerned with yellow light the cell will give far too low a reading relative to the visual estimate, a difference which becomes vastly more marked in the orange and red. In the blue on the other hand the KUNZ cell gives values which are six or more times too high. Similar cells constructed with caesium give results more nearly in accord with the eye since these are most sensitive to wave lengths around 5400, the green end of the yellow and are sensitive to about 6600, the inner side of the red. This agrees fairly well with the sensitive range of the eye to light of 500 metre candles intensity, though for sunlight the maximum is at about 5900.

But the cell is here employed not to compare visual intensities, but the effectiveness of the light as regards photosynthesis. As has been pointed out in the foregoing pages the predominant colour in water near the shore is greenish, verging to blue further out or where the amount

of suspended matter is small. Engelmann demonstrated long ago that green plants produce most oxygen in the red portion of the spectrum between the lines B and C, 6867 and 6563 Å respectively whereas the red algae are most active in the green, the colour which is complemental to their own. Kniep and Minder (1909) took the precaution of comparing lights of approximately equal intensities and found that for the monocotyledon *Elodea canadensis* assimilation was about the same in red and blue light, whereas there was but little activity in much stronger green

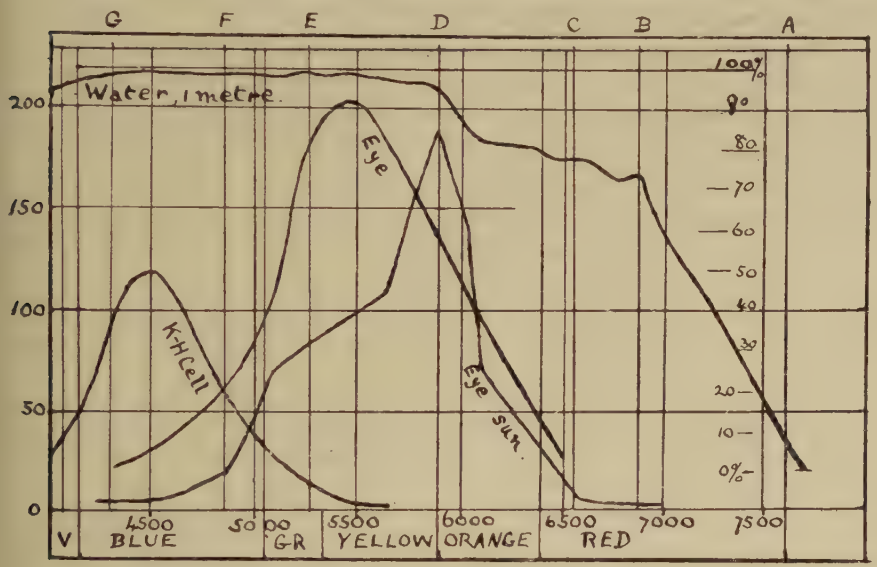


Fig. 1. From Shelford and Gail. The curves are as follows:— *KH* cell, shows its colour sensitivity; Eye, sensitivity of the eye to 500 metre candles (from Smithsonian Tables); Eye sun, sensitivity to sunlight. The ordinates on the left are arbitrary units. The abscissae are wave lengths in Ångström units. The letters above denote the positions of the Fraunhofer lines. Water, 1 m., shows the percentage (scale on right hand ordinate) of various wave lengths transmitted by one metre of pure water. The limits given for the various spectral colours are only to be regarded as approximate; in particular the true yellow is much narrower than is indicated in the figure.

light. The results have been criticized by Ursprung (1918) but as far as the writer can judge their validity has not been seriously impaired. Ursprung (1917, 1918) further concluded that some assimilation is carried out by green plants throughout the whole of the visible spectrum, and down to 3420 Å in sunlight and 3300 with arc light. It seems firmly established that red algae can utilize very effectively the blue or blue green light which predominates at 10—30 metres depth in the sea. Brown algae however, including diatoms, appear to be dependent upon

the receipt of a larger proportion of light of longer wave length than the blue. Recently KLUGH (1925, 2) has adduced evidence in support of KNIEP and MINDER's results, for he found that the green algae *Volvox aureus* and *Closterium acerosum* were able to multiply actively in red light, less so in blue, and not at all in green.

It may be of interest to speculate as to why brown and red pigments have not been developed to anything like the same extent in fresh as in salt waters. For one thing no existing fresh water bodies can at all compare in geological age with the water bathing the coast lines, which, changing themselves, have preserved the succession of their dynasty since before the sea was salt. Again the inroad of the vascular cryptogams and phanerogams, which have not developed such pigments, has been serious down to the limit of the zone we might expect to see covered by brown and red algae. Furthermore — and this is perhaps the main reason, most fresh water bodies are far less clear than the sea, for as shown by JOLY (1900) the divalent ions present in sea-water are potent in furthering sedimentation. Even those that are at times notably clear are subjected as a rule to prolonged periods of turbidity due to flood water. There is also evidence that all fresh waters, save exceptional mountain lakes with very soft water, are richer in phytoplankton than is the sea; the presence of the algal cells tends to increase the general turbidity. The effect of the latter, due largely to opaque particles of a magnitude which is considerable when compared to the wave length of light, is to cause a non-selective absorption and scattering, so that the total illumination becomes greatly reduced before the spectral character of the light has been appreciably altered, such alteration being a function of the depth penetrated. GRUBER (1924) recorded losses of illumination of from 24—85 % of that in air, at one metre, in the lakes studied by him. He worked to a depth of 4 metres using the Eder-Hecht grey-wedge, a photographic method. In addition to the large non-selective loss, there are also losses due to the selective absorption of matter in solution (such as the brownish humic substances typical of peaty water) and to the finer particles in suspension. As a result the water takes on a greenish brown colour when viewed from below, which is very distinct from the greenish blue of inshore salt water. Thus not only is the total illumination much reduced, non-selectively, but also the blue light, which is specially important in connection with photosynthesis, is cut down selectively. A brownish tint, varying from a scarcely perceptible amount to a well marked colour, appears to be typical of most fresh waters. Even lakes with very blue waters, such as those of Geneva and Lucerne are probably at times sullied by floods, though Geneva remains exceptionally clear.

To return to the potassium hydride photo-electric cell of the KUNZ type, we have seen that it affords a measure of the light intensity which is mainly that of the blue constituent of the spectrum. Furthermore we have seen that blue light is effective as regards the photosynthesis of the red algae, and from KNUDSEN's work and the earlier qualitative investigations it is plain that at depths of 10 metres and downwards the predominant light is greenish blue or blue in salt water. The readings of such a cell are therefore of value in the study of submarine illumination, though it is doubtless correct to say with KLUGH "this cell cannot give data of any value concerning either the total intensity or the spectral quality of light". Its worth is greatly increased when supplemented by information from other sources as mentioned above.

SHELFORD and GAIL had their cells standardised once for all in a laboratory, so that illuminations in metre candles could be obtained from the readings. One cell kept on deck was used to give the illumination in air, while its fellow was lowered into the water. A galvanometer was used to measure the current produced, this being possible in Puget Sound

They found that in calm clear weather between 10 a.m. and 2 p.m. about 25 % of the light is shut out by the surface of the water. In rough weather this may be increased to 60 or 70 % or more. It may however be said in criticism that these values appear unduly high, since the surface of the cell exposed to the water was spherical and accordingly, when submerged, the water, between this curved surface and the air, acted as a short focus diverging lens.

Of the light of shorter wave length entering the water they ascertained that 8—10 % reaches a depth of 10 m., a result similar to REGNARD's derived from a study of gaseous recombination and to KNUDSEN's for the blue-green and blue taken together, though for blue light only his value is 5 %, denoting more rapid absorption. In considering light intensity in relation to photosynthesis it should however be remembered that according to the thermo-electric measurements of DETLEFSEN (1888) only one per cent of the energy, in the form of light passing through the leaf, is utilized; H. BROWN (1900) gives one half per cent in sunlight and over 2 per cent in diffuse light. Lessening of the incident light may therefore be compensated by increase in the efficiency of absorption, as in the case of the red algae which look black in the blue light of deep water.

SHELFORD and GAIL tabulated the results of various physicists for pure water and have calculated the percentage transmission to different depths for thirty-seven wave lengths between 3000 and 7790 Å. Their

table shows the percentage transmitted by one metre (the coefficient of transmission), those for $n$ metres being the $n$th power of the percentage transmitted by one metre. The mean of the five determinations of the coefficient nearest to the wave length to which the cell is most sensitive is 98.07 %; it should therefore show 98 % transmission of average sunlight through pure water.

To secure the coefficient of transmission for any colour, the transmission coefficient for that wave length was first reduced to the required oblique distance coefficient, to correct for the fact that the sun's rays did not penetrate vertically. The factor SHELFORD and GAIL used for the mean altitude of the sun was 1.13. The resulting value is multiplied by a coefficient which is intended to correct for the effect of suspended matter. This was calculated from the results for blue, as measured with the photo-electric cell.

Data thus obtained were plotted and are shown in Fig. 2 from which certain lines have been omitted for clearness. The dotted curves show the percentage of the light entering Puget Sound water, which is transmitted to depths of 5, 10 and 25 metres. The full line curves show the energy of the sun's radiation, drawn to an arbitrary scale. The data used were those of ABBOT and FOWLE, for Washington D.C., and are mean values for the air thickness the rays traverse at Friday Harbour, Puget Sound, between 7 a.m. and 5 p.m. at midsummer; this thickness is equivalent to 2.00 air masses. Values for the energy $E$ at 1.28 air masses, the mean from about 8 a.m. to 3 p.m. in summer, also for 3.00 masses, the value at about 7 a.m. and 5 p.m. are also plotted. The subaquatic energy curves are shown only for $E = 2.00$ and are the products of the corresponding transmission and relative energy curves. The subaquatic secant distance for the average period when $E = 2$ is 1.31, namely the sun's rays traverse 1.31 metres for every metre of depth. The curves show that the energy available for photosynthesis lies chiefly between 4300 and 5800 Å, so the maximum sensitivity for the potassium hydrogen photo-electric cell, 4450, gives a true record of the average value of the energy curve, when the form of the curve is considered. The maximum value for the subaquatic energy curve is at about 4700 Å for the period around noon during the time of longest days. Obviously this, true for Puget Sound, will vary with the sun's altitude. The period will be prolonged in the tropics and as the sun's altitude becomes less the maximum in the subaquatic energy curve will be shifted towards 5500, which it will not pass owing to the great absorption in the red.

In calculating the transmission factors for sea water for different wave lengths it was assumed that the suspended matter and salts in

solution absorbed the light non-selectively. Thus PIETENPOL (1918) showed to be correct for suspended matter in the Wisconsin lakes, though there was also an effect due to the tint of the water occasioned by matter

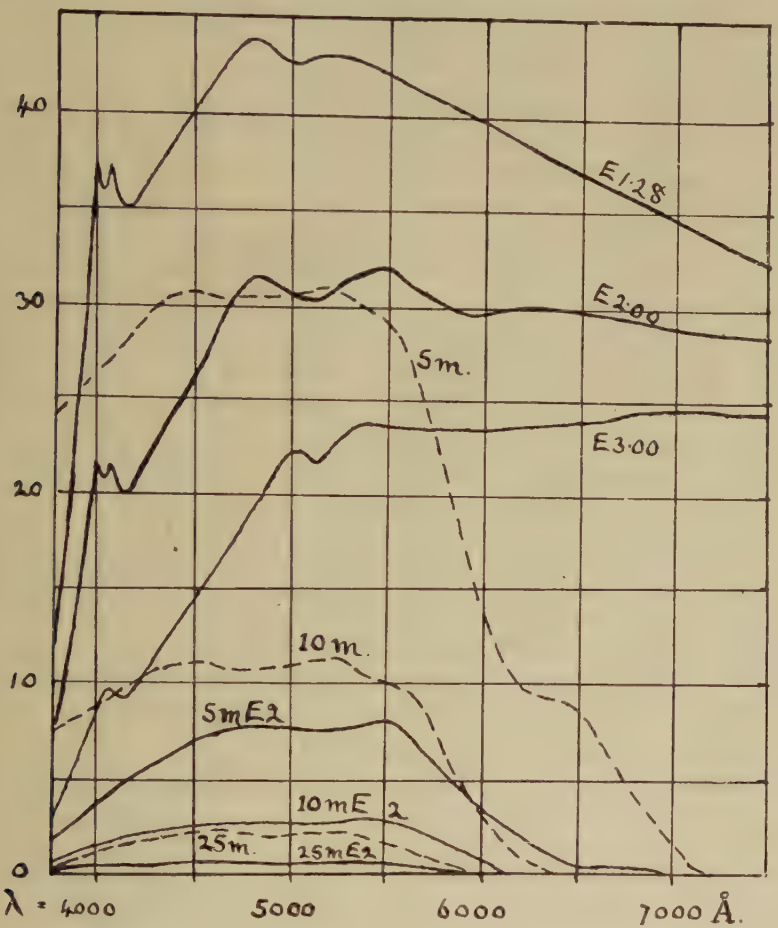


Fig. 2. After SHELFORD and GAIL. The ordinates are percentages of the sub-surface illumination and relate to the dotted curves marked 5 m., 10 m., and 25 m., which show the illumination percentage in Puget Sound water as calculated for various wave lengths of light, marked on the abscissae. The full lines are drawn to ordinates of arbitrary scale and represent the energy of the sun's light after passing through 1.28, 2.00 and 3.00 air masses, corresponding to various times of day. The sub-aquatic energy curves 5 m. E2, 10 m. E2 and 25 m. E2 are the products of the corresponding percentage and relativeenergy curves.

in solution. It may not however be strictly true for the much finer matter remaining suspended in sea-water; one would expect some selective

absorption and scattering in the region of the shorter wave lengths, the blue and violet. The effect of this would be to make measurements based on transmission of blue light too high for violet, but too low for green. The curves shown in Fig. 2 may at least be taken as giving a picture of the light conditions which prevail at the depths indicated, even though they fail to give an accurate quantitative record.

Assuming that pure water transmits 98 % per metre for $\lambda$ 4,500, i. e. the absorption coefficient is very nearly 0.02 it is evident that even in the purest surface water the bulk of the absorption is due to suspended matter, for Poole and Atkins (1926) obtained as their lowest value for this coefficient 0.11, which is less than any of Shelford and Gail's surface values. Hence it does not seem legitimate to base any argument on the relative transmissibility to various colours of pure water. Knudsen's results indicate that the absorption in sea-water is not non-selective and as by far the greater part of this must be due to suspended matter it seems clear that the latter must have a selective action. It is evident then that Shelford and Gail's calculated results as shown in Fig. 2 would not be applicable to the less clear water of Nyborg Fjord, but may be taken as of some value for highly transparent water, in which the suspended matter being small, the fact that its action is somewhat selective in cutting out the blue is necessarily of reduced importance. It is not disputed at all that the grosser suspended matter, which is especially plentiful in fresh water, acts non-selectively.

Table 5 shows Shelford and Gail's measurements for illumination in metre candles, taking their mean values down to 120 m.

Table 5.

| m | Illumination in metre candles, average of all results | % | % |
|---|---|---|---|
| Air | 93,100 | 100 | 132 |
| 0 | 70,500 | 75.7 | 100 |
| 10 | 8,930 | 9.6 | 12.7 |
| 25 | 3,605 | 4.0 | 5.1 |
| 35 | 2,217 | 2.4 | 3.1 |
| 50 | 1,388 | 1.5 | 2.0 |
| 75 | 796 | 0.88 | 1.1 |
| 100 | 408 | 0.44 | 0.58 |
| 120 | 150 | 0.16 | 0.21 |

In order to carry out similar photo-electric determinations in the rougher waters of the English Channel Poole (1925) modified Shelford

and GAIL's arrangement. The photo-electric current from the KUNZ cell was passed through a known high resistance, the potential difference between the ends of the latter being balanced against a potentiometer. A telephone was used as a detector instead of a galvanometer. In order to enable this to be done the telephone circuit was interrupted many times a second by a special form of interrupter. The interposition of a two-stage valve amplifier increased the sensitivity. A vacuum photo-electric cell was used as a standard and to record fluctuations in the surface light. The readings of this vacuum cell are very approximately proportional to the light as shown by the Research Department of the General Electric Company (1924) whereas the sensitivity of the KUNZ cell was observed to vary according to its previous history — an exposure to high light intensity causing it to read too high.

POOLE paid special attention to the optical conditions of his apparatus and made corrections for the effect of obliquity and for reflection losses. His KUNZ cell was mounted in a stout gun metal case, somewhat similar to REGNARD's, with a matt diffusing varnish on the interior surface of the window. The vacuum cell was similarly mounted just below a ground glass window and gave readings such that one potentiometer scale division corresponded to 195 metre candles; the KUNZ cell was about from 2.5 to 40 times as sensitive according to the anode potentials used, so that one scale division corresponded to from about 80 to about 5 metre candles, but this factor varied independently of the anode potential and had to be checked once or more often in each series.

As pointed out by POOLE, this arrangement measures the illumination on a horizontal surface, as was the case with the measurements of most other workers, whereas for the photosynthesis of a unicellular plant in the sea all light regardless of angle is effective. For perfectly diffused light coming from the upper hemisphere only it may be shown that the total illumination is twice that on a horizontal surface. Curves were given from which the total illumination can be found if the altitude of the sun and the ratio of direct sunlight to diffuse sky-light are known. With a clear sky the sunlight was found to be about two thirds of the total. These measurements were carried out on a pier in Cawsand Bay, Plymouth Sound, or on a boat off the pier. They bring out clearly the effect of the variations in the turbidity in such water, for the coefficient of absorption $\mu$, varied from 0.7 on a day when the water was obviously sandy, to 0.25 in calm weather a few days later, taking average values. The absolute maximum and minimum values were $\mu = 0.81$ and 0.165, excluding results affected by surface losses. In other words these extreme losses indicate that the light which has entered the water is reduced to

$\frac{1}{e}$, viz. $\frac{1}{2.718}$ or 0.37 approximately, of its original value after traversing 1.23 and 6.06 metres respectively. The actual depths would be somewhat less, according to the obliquity of the rays. It may be recalled that KNUDSEN's value for blue light was $\mu = 0.300$; Nyborg Fjord water may accordingly be taken as similar to that of Cawsand Bay in moderately calm weather, the coefficient corresponding to a reduction to 0.37 of the initial sub-surface illumination in a path of 3.33 metres. How great is the effect of the suspended matter may be realized when it is noted that in pure water 37.1 % of the entering light is transmitted vertically to a depth of 50 metres, the wave length being 4750 Å, a length to which the potassium cell is quite sensitive, whereas light of 4490 Å — the most sensitive region for this cell — only falls to 37 % at about 82 metres.

An idea of the submarine illumination at 10 metres under the different conditions may also be obtained as follows:— since as given previously $I = I_0 e^{-\mu x}$, where $x$ is the thickness of water traversed, namely the depth for vertical lighting, it follows that $I = 100 \times \frac{1}{2.718^{0.165 \times 10}}$ for the clearest Cawsand Bay water and $I = 100 \times \frac{1}{2.718^{0.81 \times 10}}$ for the turbid day; these give 19.2 % of the sub-surface light penetrating 10 metres of clear water, 0.033 % being the corresponding value for the turbid. The same result is obtained from the figures given before, viz. for example, the turbid water reduces the illumination to 37 % in 1.23 metres, and so on for each of the 8.1 times that 1.23 is contained in 10. But the clearer water reduces the illumination to 37 % in 6.06 metres, and this process is only repeated 1.65 times in the 10 metres.

Such considerations enable one to see why it is that red algae are most favoured by clear water, for under turbid conditions the zone they normally occupy, in which their adaptation to blue light gives them an advantage, has become too dark for them. The shallower zone is fully occupied by brown algae as though the light intensity has been reduced by the turbidity the spectral character of that light has not been sensibly modified by the gross particles in suspension. This it will be appreciated is merely another application of the principle that has already suggested a reason for the absence of any notable development of red algae in fresh water.

The apparatus devised by POOLE was further used by POOLE and ATKINS (1926). It was ascertained that the loss of light caused by surface reflection was not so large as has been recorded by some other workers, but varied from 5—31 % according to conditions; the least loss was with glassy water and a grey sky, the greatest was with a fresh N.W.

wind causing waves to break, viz. "white horses" without much swell. These measurements were all carried out on a trawler, and the apparatus worked satisfactorily even when the vessel was rolling heavily.

A summary of the results of six series of determinations is given in Table 6. Appropriate corrections were introduced for the angle of incidence of the light. In the first column, under $V$ in air, is recorded the mean value of the vertical illumination for the deck photometer during the series, recorded as thousands of metre candles. The surface transmission percentages, both as found and as calculated for a smooth surface are next recorded. Under $\mu'_1$, $\mu'_2$ and $\mu'_3$ are given the vertical absorption coefficients from 0—10, 10—20 and 20—30 metres respectively, $\mu_1$, $\mu_2$, $\mu_3$ being the corresponding true coefficients as corrected for the length of the path traversed by the rays. It should be noted that the coefficient given by KNUDSEN corresponds to $\mu'$ not $\mu$, but as he measured light making only a small angle with the vertical $\mu'$ and $\mu$ are almost identical. $D$ is the depth in metres at which the photometer window, which, owing to the matt varnish, appeared from above as a white disc (6.6 cm. in diameter), was just visible and $P$ is the percentage of the illumination in air corresponding to this depth.

Table 6.

| Series | V in air. m. c. Multiply by $10^3$ | Surface transmission | | Absorption coefficients | | | | | | Disc visibility in water | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Vertical | | | True | | | | |
| | | % obs. | % calc. | $\mu'_1$ | $\mu'_2$ | $\mu'_3$ | $\mu_1$ | $\mu_2$ | $\mu_3$ | D, m | P % of V, air |
| 1... | 45 | 83 | 93.5 | 0.267 | — | — | 0.224 | — | — | — | — |
| 2... | 70 | 90.5 | 96 | 0.148 | 0.163 | 0.164 | 0.122 | 0.135 | 0.136 | 7.0 | 33 |
| 3... | 16 | 86.5 | 93.5 | 0.234[1]) | — | — | 0.196[1]) | — | — | 4.2 | 37.3 |
| 4... | 68 | 69 | 96 | 0.139 | — | — | 0.115 | — | — | 5.9 | 30.5 |
| 5... | 32 | 79.5 | 95 | 0.131 | 0.138 | 0.296 | 0.110 | 0.116 | 0.248 | — | — |
| 6... | 20 | 95 | 94 | 0.134 | 0.143 | 0.162 | 0.110 | 0.117 | 0.133 | 8.9 | 28.3 |

[1]) From measurements down to 6 m. only.

Series 1, 3 and 4 were carried out in Cawsand Bay, well out from shore in depths of about 12, 18 to 10, and 11 m. respectively. Series 2 and 5 were made about 3 miles S. of the Mewstone, to east of Plymouth Sound in the open sea depth 40 m. The measurements of Series 6 were made at International Hydrographic Station E1, about 20 miles from land, depth 72 m. All were made early in Sept. 1925, save No. 6 on Oct. 1st.

It will be noticed that there is an increase in the coefficients as the

bottom is approached, and that the water is rather clearer at E1 than closer to the shore.

The values are all smaller than those found on Cawsand Pier in 1924. The offshore values down to 20 metres are somewhat less than those given by SHELFORD and GAIL on p. 162 of their paper, where, however, transmission coefficients are given. Thus in spite of the lower solar altitude the mean of series 2, 5 and 6 in the English Channel gives an illumination at 20 metres which is about 5.5 % of that just below the surface, whereas their mean figure is 2.5 % (p. 156). Thus the surface water in the English Channel was then somewhat clearer than that in Puget Sound, though the reverse was true of the deeper water, owing apparently to sediment from the bottom in the relatively shallow Channel.

The values for $D$ and $P$ are of some interest in connection with the large number of observations made with SECCHI's disc, although they are not strictly comparable, since the photometer window is only about one third of the diameter of the disc, and is probably not so white. Apparently the limit of visibility is reached when the vertical illumination has been reduced to about one third of that in the air. This appears to be nearly independent of the actual value of the surface illumination over a wide range in fact till the onset of dusk, as was shown by measurements made specially to test the point.

The illuminations determined at various depths in the six series summarised in Table 6 are shown graphically in Fig. 3 in which the depth in metres is plotted against the logarithm of the vertical illumination, in metre candles. The scale however is marked like a slide rule and the actual illuminations may be read off from it. The surface loss is given by the intercept, on the line denoting the water surface, between each curve and the vertical line indicating the air illumination. The prolongation of each curve to cut the corresponding vertical shows, by the height of point of intersection above the surface, the depth of water which would cause an equivalent reduction in light.

As an example of the precision with which POOLE's apparatus can be worked it may be mentioned that in Series 6 two determinations were made at 34.8 metres depth, an interval of an hour and a quarter separating them. During this period the illumination in air changed from dull, 17,400 metre candles to weak sunlight 24,500 m.c., yet, when the two determinations were worked out, in each case the value was 0.54 % of the illumination in air.

From the foregoing pages it is clear that the photosynthetic activity of the phytoplankton is chiefly confined to the upper 10 to 20 metres, and that within this limit the first five metres is probably the most

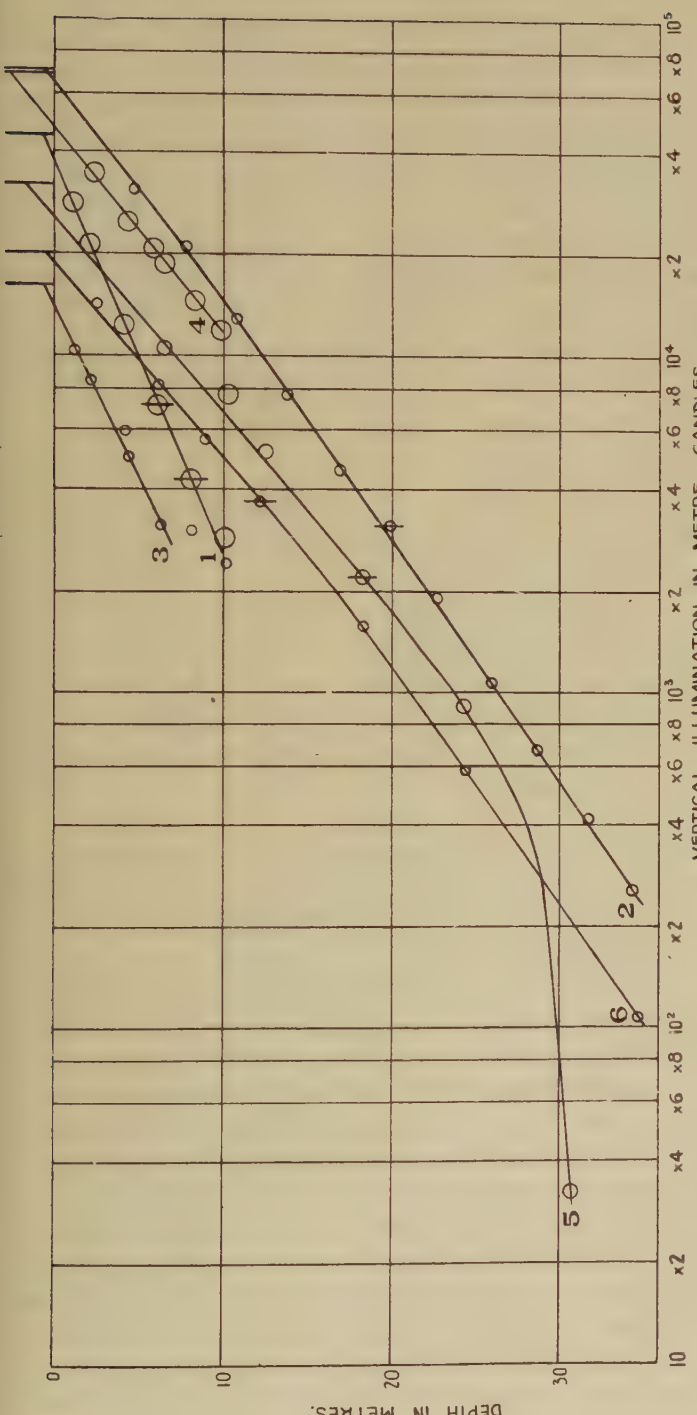


Fig. 3. From Poole and Atkins. The scale of the abscissae is logarithmic, but the numbers underneath read directly. Curves Nos. 1, 3 and 4 relate to Cawsand Bay. Nos. 2 and 5 to measurements in 40 m. three miles from land. No. 6 concerns a series at Station E1, 72 m. depth, 20 miles from land. The stroke through the circle indicates the depth at which the voltage used with the photo-electric cell was changed from 120 to 20 on ascending.

important zone in early spring when the submarine day is very short.

It is recognised that this survey of submarine illumination is incomplete. No mention has been made of the notable investigations of Grein (1913) or of Helland-Hansen (1912) upon the spectral character of the light in deep water, or of various other researches referred to in the papers of Klugh and of Gruber. The data summarised include however the more important quantitative measurements which are concerned with those depths in which photosynthesis takes place. The results quoted will also be found to have a bearing upon the vertical movements of the macroplankton as studied for example by Russell (1925, 1926).

### Measurement of total submarine radiation.

Heretofore the radiant energy incident upon the water has been considered only so far as the visible portion of the solar spectrum is concerned. Birge however made an exhaustive study of the total radiation by means of Mendenhall's (1922) pyrlimnometer. This consists of a receiver containing twenty small thermocouples which can be lowered into the water to any desired depth and alternately exposed to the sun and covered. The current thus generated is measured by the deflections of a d'Arsonval galvanometer on shore, which is connected with the receiver by an insulated cable 100 m. long.

The observations made on Lake Seneca, New York (Birge and Juday 1921) as shown in Table 7, serve to illustrate the results obtained, and the discussion which follows is taken almost verbatim from their paper, with abbreviations.

Lake water differs widely from pure water in the quantity of energy transmitted. In passing through the first metre the water of Seneca Lake adds one half to the loss due to pure water. Pure water transmits through the 1—2 metre stratum nearly 80 % of the energy reaching its upper level and over 90 % passes through all deeper one metre strata, the loss per metre rapidly declining to a minimum of about 2 % of the energy incident on the upper surface of each stratum. In the lake water each metre stratum below the surface metre transmitted about 71 % of the energy received. The great difference between pure water and lake water is probably due chiefly to suspended matter as there was very little tint in the water due to substances in solution.

The suspended matter was partly organic, but chiefly fine silt.

In pure water the transmission through the 1—2 m. stratum is much

smaller than in those below. This is due to the rapid absorption of the rays of the red end of the spectrum as compared with that of the shorter waves. No such effect seems to be present in Seneca Lake, nor is it ordinarily demonstrable in lakes. Sometimes, but not commonly, the deeper strata show a transmission 1 or 2 per cent higher than the 1 to 2 m. stratum, but in general the transmission in that stratum is nearly the same as in those immediately below. This means that the large non-selective absorption due to turbidity and the selective absorption due to the tinting of the water obscure the effect of the selective absorption

Table 7. Radiation in calories per square centimetre per minute in Lake Seneca, Aug. 1, 1918. The last percentage column shows approximate values for pure water.

| m | Cal./cm²/ min. | % | m | Cal./cm²/ min. | % | m | % |
|---|---|---|---|---|---|---|---|
| In air | 1.30 | 100 | 3.50 | 0.12 | 9.0 | Air | 100 |
| 0.25 . . . . | 0.41 | 31.8 | 4.00 | 0.10 | 7.7 | 1 | 47 |
| 0.50 . . . . | 0.38 | 29.0 | 5.00 | 0.07 | 5.4 | 5 | 29 |
| 1.00 . . . . | 0.28 | 21.4 | 6.00 | 0.05 | 3.8 | 10 | 23 |
| 1.50 . . . . | 0.23 | 17.4 | 7.00 | 0.035 | 2.7 | | |
| 2.00 . . . . | 0.20 | 15.0 | 8.00 | 0.023 | 1.8 | | |
| 2.50 . . . . | 0.17 | 12.8 | 9.00 | 0.017 | 1.3 | | |
| 3.00 . . . . | 0.14 | 10.9 | 10.00 | 0.013 | 1.0 | | |

of the water, as water, after the first metre has been passed. In that metre is absorbed practically all of the energy contained in the portion of the spectrum lying below the *A* line ($\lambda = 7594$ Å), which is commonly taken as the lower limit of the visible spectrum.

The percentages given in Table 7 vary somewhat with the sun's altitude. Under the conditions prevailing at the time, the sun's rays passed through 10.0 metres in reaching a depth of 9.4 m.

Birge and Juday also pointed out that the direct sunlight supplies about two thirds of the radiant energy received by the lake, the remainder coming from the sky during sunshine and in cloudy periods.

It is obvious from the foregoing considerations that the surface two metres of the water receive almost all the heat. Work must therefore be done in mixing the warmer upper metres with the cooler, and therefore heavier, lower layers. Their investigation of this point led them to think that 84 to 92 per cent of this work is performed by the wind, so far as the mixing extends in summer. Surface evaporation also, in virtue of its cooling effect, and in the case of salt water by concentrating the

upper layers must contribute to the mixing; the evaporation effect is of course not unconnected with that due to wind (see ADENEY, 1925).

As winter approaches the cooling of the upper layers renders the mixing automatic and the isothermal column, which results in the shallower lakes and seas of the temperate zones at least, offers little opposition to the action of the wind — and the waves due to it — in maintaining the water column in a far more homogeneous condition than it is in the summer months.

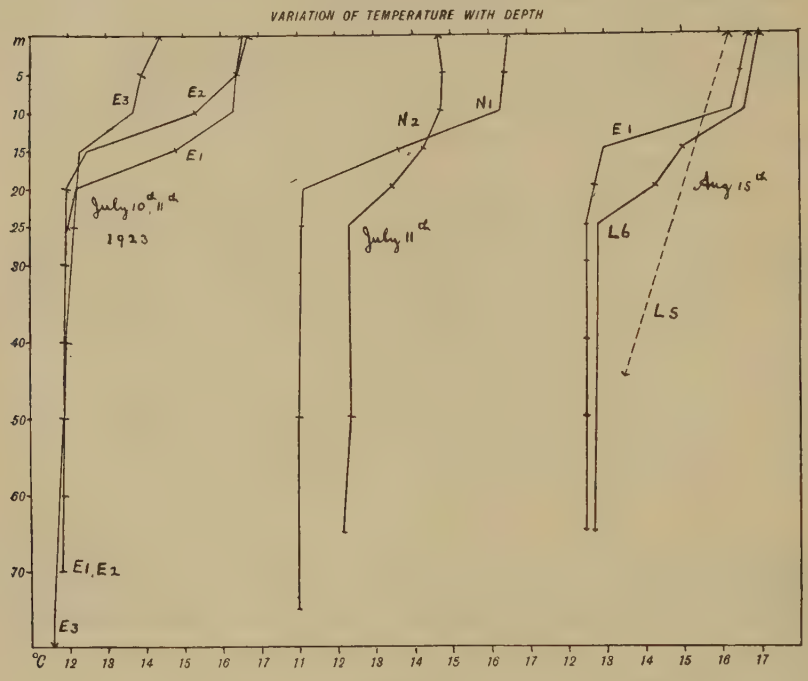


Fig. 4.

The phenomena of thermal stratification are of great importance for the development of the phytoplankton, for as will be shown later the supply of nutrient salts is regulated thereby. Such stratification has been considered at length by BIRGE and JUDAY (1911) in their limnological studies. BIRGE (1910) designates the upper warm and the lower cold layers the "epilimnion" and "hypolimnion" respectively. These terms, connoting very different biological habitats are undoubtedly useful, but from their derivation are not strictly applicable to sea water. The writer (1925) accordingly suggested that the terms "epithalassa" and "hypothalassa" should be used to denote these layers in sea water, the region between them being denoted by the well-established term

thermocline, introduced by Birge in 1897. In the Greek "epilimnion" and "epithalassa" denote their respective margins rather than upper water layers.

The magnitudes of temperature differences found in the English Channel are shown in Fig. 4 (1924), the stations being as follows:— E series, the International Hydrographic Stations from outside Plymouth to Ushant; L5, close to the Eddystone Light House, L6 half-way on

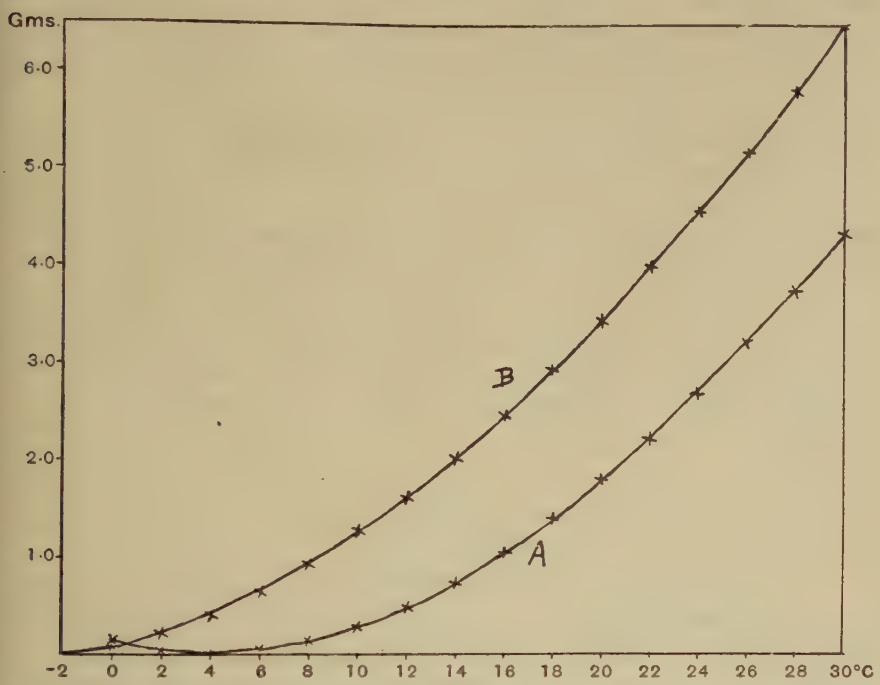


Fig. 5. The curves represent changes in density due to rise in temperature. The ordinates show differences in weight, in grams, between a litre of water at temperature $t°$ and 4°, curve A, and between $t°$ and $-2°$, curve B, which is for water of salinity 35.3 ‰. For example, in B, $D_{\frac{-2}{4}} = 1.02845$ and $D_{\frac{14}{4}} = 1.02644$, viz. 2.01 gms. less per litre, as may be read off on the curve.

towards E1; N1 and N2 are on the line from Ushant to Cork Harbour, N2 being S. of the Bishop Light off the Scilly Is. The epithalassa often persists throughout the summer months; though the rough seas of June, 1922, almost destroyed it, yet it became apparent again in August. Its stability is, in fact, surprising, but Birge (1910) has given reasons which render the persistence of the epilimnion intelligible. These apply to the epithalassa equally or rather more forcibly.

The effectiveness of the resistance to mixing, due to increase of temperature, is not proportional to the temperature gradient simply, but depends also on the departure of this temperature from that of the maximum density of water. In Fig. 5 are plotted the temperature — density curves for both fresh and salt water as explained in the legend. Owing to the differences in the temperature of maximum density more work is required to mix a cubic metre of salt water than of fresh; each being, for example at 16° at the top of the cube and at 14° at the bottom, the number of ergs required are 3997 and 2899 respectively. It follows that a salt water column is more stable than one of fresh water at the ordinary air temperatures.

The biological significance of the vertical mixing of the water will be considered in some detail later.

In concluding Part I the writer wishes to record his indebtedness and to express his thanks to Dr. H. H. Poole, under whose guidance he ventured to take up the study of submarine illumination, for much helpful criticism, also to Prof. H. H. Dixon for revising the manuscript. He also wishes to thank Dr. E. J. Allen and Mr. H. W. Harvey for assistance with the literature of the subject, and the Marine Biological Association of the United Kingdom for the loan of the blocks for Figures 3 to 5.

## Summary.

Data have been presented concerning the depths at which fixed algae are found; these serve as a basis for a guess as to the depth at which diatoms and peridinians can produce carbohydrates in excess of their immediate requirements for respiration. Researches dealing with submarine illumination have been considered and it has been shown that for the blue portion of the spectrum the cofficient of absorption, $\mu$, may vary as widely as from 0,81 for shallow water turbid with sand to 0,11 for clear water in the English Channel — the actual limits being doubtless much wider apart. Even in the clearest water the diminution in light-intensity as depth increases is mainly due to matter in suspension, since for pure water $\mu = 0{,}02$ approximately. Fresh water is usually far less clear than is salt water. When the total incident radiation is considered it is found that by far the greater portion is absorbed by the surface two metres. The importance of the thermal stratification of the water has been discussed in relation to its importance as limiting the circulation of nutrient salts.

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# A new Current Measuring Instrument for the Purposes of Fishery Research

by

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(Fisheries Laboratory, Lowestoft.)

**With a technical description by**

**H. J. Garrood,** A. M. I. Mech. E.
(Messrs. Elliot and Garrood, Beccles, Suffolk.)

**and a contribution by**

**T. Edser,**
(Chief Statistical Officer of the Fisheries Department of the Ministry of Agriculture and Fisheries.)

## Introduction (by J. N. C.)

The need for knowing all that is possible about the water movements in a sea area is admitted by all workers engaged upon fishery research. It is imperative, for instance, if a satisfactory knowledge of plankton distribution be sought, that the observed distributions be related to what is known of the marine currents, so that one may be able to predict future distributions. The fate of newly spawned fish eggs and of passively transported fish-fry are also dependent upon the water movements. It is quite unnecessary to labour the point here; suffice it to say that for the general purposes of fishery investigations many extensive hydrographical researches have been launched to afford information in this connection. Probably the most useful instrument in the hands of the fishery researcher has been the drift bottle. In the past many thousands of freely floating and bottom trailing bottles (all containing questionnaire papers for the use of the finders) have been put out at different places, and very useful information has resulted. The movements of the bottles indicate what are the water movements — at surface or bottom as the case may be — over and above the tidal oscillations.

The information they afford, however, has many shortcomings, and it is frequently the case that one wishes to know the actual set of the

current in a certain region. To obtain this knowledge one might carry out a very intensive and long-maintained series of current measurements with a view to balancing out the tidal oscillations and thereby obtaining the direction and speed of the overall set. Such a task demands considerable personnel, and furthermore it is very laborious. The idea arose that it would be very convenient to have an instrument designed to yield the information sought without great expenditure of time and labour. Such an instrument has been made and successfully worked.

A short description of the original experimental model, together with an account of one observation obtained with it, has already appeared ("Nature" 15th. November 1925). The instrument embodies certain features of the Robinson Anemometer and makes use of the very ingenious direction recording mechanism due to EKMAN[1]), and well known to all users of the EKMAN Current Meter.

The direction of the current is recorded as follows in the instrument just referred to: —

A propeller rotates under the force of the current, and from time to time it actuates mechanism which allows a little phosphor bronze ball to fall from a small tubular reservoir on to a pivoted compass needle. This needle has a runway on its North seeking end down which the ball rolls. The compass needle is pivoted centrally above a cylindrical receiving box which is divided by thin partitions radially disposed, into a number of sectors — in EKMAN's original model 36 sectors were provided. Now, as a ball is released, it will fall on to the needle and roll down into one of these sectors, and, since it rolls down the North seeking end of the needle the sector into which it falls must at the time be facing North.

It becomes then a question of labelling the various sectors properly so that one may know what direction they represent. This is done as follows: —

(a) **Consider a North going current.**

The after end of the instrument will be to the North and so will the runway on the compass needle. Hence that sector due aft (nearest to the vanes) will receive the balls and must be labelled "N".

(b) **A South going current.**

The forward end of the instrument (the propeller or cups end) will face North and so will the runway on the needle. Since the current

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[1]) See Publication de Circonstance No. 24.

is South going that sector nearest the propeller or cups (the forward sector) will receive the balls and must be labelled "S".

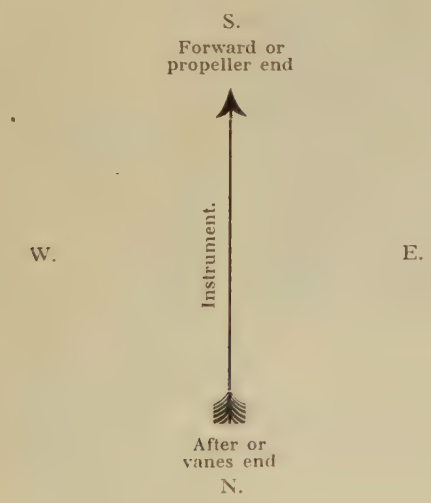
(c) **An East going current.**

The vanes will face East and the runway on the compass needle will of necessity face North. Hence that sector of the receiving box which now faces North must be labelled "E". i. e., the sector on the right flank of the instrument (as it would appear to an observer straddling the instrument and facing forward) must be so labelled.

(d) **A West going current.**

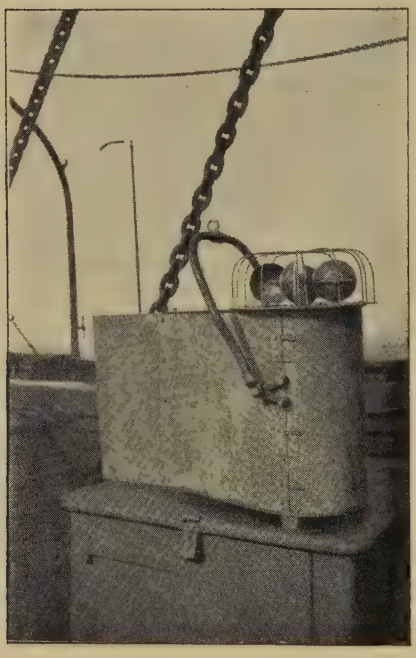
The sector on the left flank as viewed by our observer will be labelled "W".

It follows that the sectors must be labelled according to the following scheme: —




The actual instrument (hereafter referred to as the "Drift Indicator") is amply described in the accompanying contribution by Mr. H. J. Garrood, who has been responsible for its construction. To Mr. Garrood are due the writer's thanks for the very satisfactory way in which he built up the instrument from the ideas submitted. The shot referred to in Mr. Garrood's article are phosphor bronze balls of $\frac{5}{32}$ inch diameter. Of these the hopper can accomodate somewhat more than 150 gross — as was ascertained by a count very kindly carried out by Messrs. The Hoffman Manufacturing Company Limited, of Chelmsford. The actual

count showed the hopper to have capacity of 21,622 balls. The Drift Indicator as delivered from the manufacturers (Messrs. Elliott and Garrood Limited of Beccles, Suffolk) weighs about 65 lbs. (= 29.5 kilos). Added to this must be reckoned the weight of the two lead sinkers customarily used with it to minimise the extent to which the instrument will be carried aft when suspended from a vessel anchored in a tideway. These sinkers weigh 15 lbs. (6.8 kilos) each, and they are suspended by brass chains slung from small brass shackles engaging in the holes in a fore and aft bar fitted underneath the Indicator. The provision of this bar having holes along its length enables proper balance of the instrument to be obtained.



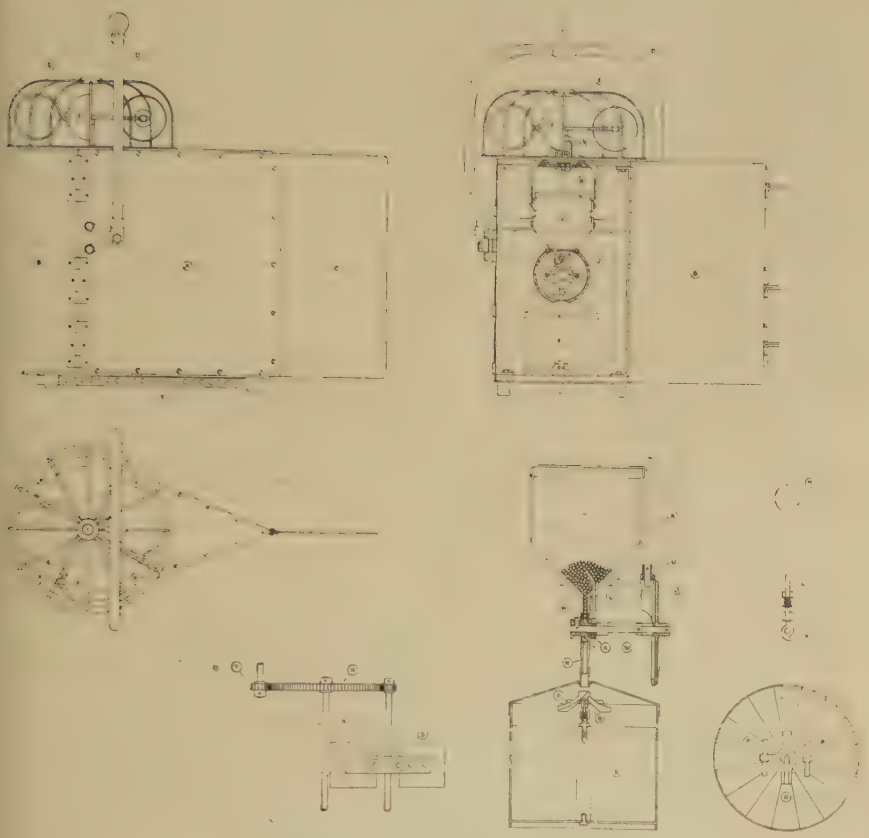
The Instrument

It has been found convenient in practice to work the instrument on $2^1/_2$ inch Manilla rope, though a considerably less stout suspending line would suffice. The supporting block is hung from a strong spring which acts as a shock absorber when the vessel is pitching. As an example of the robust nature of the Indicator, it may be mentioned that it was worked for 2 days during the prevalence of a No. 9 southerly wind on the Saint Nicholas Lightvessel off Great Yarmouth. A photograph of the instrument is here reproduced.

**Description of the Drift Indicator** (by H. J. G.)

The Drift Indicator consists essentially of a prime mover F. driving through gearing H. and J. a shot dropping wheel M; a shot hopper I; a magnet shot distributor O. and a shot receiver R; the whole being assembled on a framework covered with sheet brass, the covering being extended to form a rudder C. which keeps the Indicator in the stream.

The prime mover F. consisting of four cups each mounted on a separate arm of a spider, rotates through gearing a shot dropping wheel M., this wheel taking shots from the shot hopper I. above, and dropping



Diagrams.

them on to the centre of a magnet O. of special shape, one side of which provides a runway for the shots. The shot drops from the magnet into the receiving box R. below, this box being divided radially by thin partitions into equal angular spaces. These spaces are numbered and thus record the direction in which the Indicator is pointing at the time of dropping each shot.

The driving cups F. which are driven by the tidal pressure of the water are adjustable outwards from, or inwards to, the centre on their respective arms, and are held in position on the arms by clamping screws.

The pinion T. on the lower part of the first driving spindle engages with a spur wheel H., this part of the gearing giving a ratio of reduction in speed of 10 to 1.

At the bottom of the second driving spindle X. is fixed a bevel pinion U., the spur wheel H. being fixed to the upper end of the spindle.

This bevel pinion U. engages with a crown wheel J. which is fixed to a horizontal shaft W. At the opposite end of the shaft W. is fixed the shot dropping wheel M.

The bevel gears U. and J. again give a ratio of reduction of speed of 10 to 1, so making the overall ratio of reduction of driving cups to shot wheel 100 to 1, i. e., the driving cups F. make 100 revolutions to one revolution of the shot dropping wheel M.

Three shot dropping wheels are provided, one wheel having one shot recess only on its periphery, one with two recesses and one with three recesses.

By using these respective wheels the number of shots dropped per 100 revolutions of the driving cups may be one, two or three.

The shot hopper consists of a plain cylinder inside with a conical bottom, the apex of which continues into a rectangular shaped slot which extends downwards on to the shot dropping wheel.

A disturbing rod L. projects into the hopper at its lower part and is operated by a cam K. formed on the shot dropping wheel. The rod is evenly raised and suddenly dropped by means of the cam and a returning spring, so disturbing the shots at the bottom of the hopper and by preventing the shots jamming ensures that they fall into the rectangular slot at the bottom and on to the wheel.

A pawl and pawl race V. situated below the driving cups and operating on the first spindle prevents the rotation of the cups in a reverse direction, and consequently ensures the rotation of the cam K. in one direction only.

This prevents the disturbing rod L. being jammed against the sharp rise on the cam, which would occur if the direction of rotation of the cam were reversed.

The magnet comprises a magnet holder O. and two steel magnetised rods P. the latter being held in the magnet holder by clamping screws. The top centre of the magnet holder is in the form of a cup and a runway for the shot extends from this cup to the edge of the holder. An agate centre is provided in the bottom centre of the holder and the whole magnet is mounted on a needle pointed pivot held in the shot receiver R.

A "flyer" S. driven off the spur wheel H. and rotating in water at the same speed as the driving cups, provides the necessary damping action to smooth out slight and sudden variations in the strength of the current driving the cups. This flyer may be taken out of gear if considered unnecessary at any time before lowering the Indicator.

The whole Indicator is suspended by the sling D., balance being maintained by lead weights which may be suspended from any position in a "fore and aft" direction on the balancing bar T.

### The Testing of the Instrument (by J. N. C.)

The initial tests of the experimental model were carried out on the Saint Nicholas Lightvessel situated about $1^1/_4$ miles off Great Yarmouth, and thanks are here expressed to the Elder Brethren of Trinity House who permitted this, and to the District Superintendent of the Trinity Corporation's Yarmouth Depot, who very kindly afforded all possible facilities. Naturally various defects were found to exist, and repeated visits were made to the lightvessel until it was possible to say that the instrument was satisfactory. Difficulties arose in connection with the magnet, and a very stable, strong, and serviceable type was finally evolved. As now used the magnet is coated with cellulose acetate enamel to prevent corrosion[1]). The crew of the lightship were quite well able to work the instrument themselves after a short experience of it, and at the present moment two Drift Indicators are at work continuously on the Varne and Smith's Knoll Lightvessels respectively. Having ascertained that the instrument was sufficiently robust to work satisfactorily under the conditions for which it was designed, the calibration was undertaken.

### The Calibration.

Permission was obtained to use the Lowestoft Municipal Swimming Pool for this purpose. The instrument was fitted with a "Veeder" revolution counter to indicate the number of revolutions made by the cups. Then by dint of suspending the instrument from the end of a boom carried on a truck which could be moved along the edge of the pool, it was towed over a chosen distance at varying speeds. The chosen distance was 100 feet, and a table was worked out showing at what speed this distance had to be traversed to ensure that the speed of towing would be $^1/_4$, $^1/_2$, $^3/_4$ —— $4^1/_2$ knots. It was not possible to tow the instrument at a greater speed than $4^1/_4$ knots. Practice walks over the distance were made to find the rate at which it would be necessary to move to attain a desired speed. When practice had enabled the observers to cover the distance at an uniform speed in the required time, the towing was done, the revolution counter being read before and after the tow. It was found possible to tow over a range of speeds from $^1/_2$ to $4^1/_4$ knots. Examination of the revolution counter readings indicated uniform registration for speeds varying downwards from $4^1/_4$ knots to 1 knot. Below this latter speed the registration fell off very slightly, though the amount could not be ascertained with great precision. The constancy of the number: — "revolutions registered" over the range of speeds

[1]) See Addendum.

indicated, was considered satisfactory for the uses to which the instrument was to be put. Having carried out the foregoing trials it was decided to conduct a calibration test from the Saint Nicholas Lightship. A suitable log line was prepared as follows: —

Two pieces of wood about $^1/_2$ inch thick and of size about 1 foot square, were fitted together to form a right angled cross. A small tin can was hung from the bottom of this cross, and a thin, casting line attached to the top. The can was weighted with small lead shot until the log-ship floated just awash and a length of line equal to $^1/_{20}$th. of a sea mile was marked in a suitable manner. Preliminary trials of the strength of the tidal streams were made, and it was found possible to arrange that the Drift Indicator should be put over in a good stream persisting with practically no change in strength for upwards of 2 hours. The instrument was put out so that it was just below the surface, and it was left down for 2 hours. During this period the log-ship was continually used and the time taken for the $^1/_{20}$th. sea mile to run out determined every 5 or 10 minutes. Thus it was possible to find the mean speed of the stream throughout the period chosen, and therefrom to calculate how many "miles of water" had flowed past the vessel. On heaving in the instrument the number of shot dropped was counted and the "mileage value" of the balls determined. In the instrument first tested 28 balls were dropped per mile of water. In instruments subsequently received and tested the corresponding figures were 28 and 29.

### The Drift Indicator in Use.

Since the instrument employs a magnet to indicate the direction of the current, it is essential that all due precautions be taken to ensure that the magnetic field of the observing vessel has no disturbing effects. Ideally the observations should be carried out on wooden vessels such as the majority of the English Trinity House vessels are. On these vessels the disturbing magnetic effects are minimal, and the vessels are large enough and carry a sufficiently large crew to render the use of the Indicator easy and convenient. Usually a boom is swung out and the instrument lowered on a $2^1/_2$" Manilla rope over a suitable block which is hung from a spring, the latter to absorb any shock due to the vessel pitching. The thick rope enables the instrument to be hauled in easily by hand. Since it is intended that the Indicator shall be left down for a very considerable time, no messengers to operate releasing mechanism are used. The instrument can be lowered to the required depth quickly, and the rotations of the cups occurring during descent and ascent may

be considered of negligible importance. Consideration being paid to the large shot-holding capacity of the hopper, there is no reason why the Indicator should not remain down for upwards of two weeks. Actually, it is better to work it for shorter periods so that if any defects have developed they may be attended to; this obviates the serious loss of time which would arise if the Indicator were left down for a long period without working satisfactorily. It has been found convenient to work the Indicator for a chosen period (usually one lunar day of 24 hours, 50 minutes) having put it out preferably at slack water, then to bring it inboard and remove the balls from the receiving chamber in the following manner. By means of the "pouring out disc", which is a circular sheet of brass having a piece equal in width to one of the sectors cut from its periphery, the balls can be poured from each of the sectors in turn into small calico bags appropriately numbered. Thereupon the instrument can be immediately put over again if the working has been satisfactory, and the balls which have been removed counted at leisure. The recording is very simply done, as the forms provided bear a picture of the radially divided receiving box, and it is merely necessary to write in the proper places the numbers of balls found in the various compartments. Using the above method of working it is easy to bring the instrument inboard, empty it, and put it out again within the space of 5—10 minutes. It is, however, intended that a spare receiving box shall be used so that the time "out of the water" may be even further lessened. The fact must be borne in mind that what is being investigated is the residual water movement, since this is the quantity of interest to the fishery researcher. Hence the 5—10 minutes missed (and this usually at slack water) are of little importance. Acquaintance with the instrument soon yields information as to its capabilities, and it has sometimes been found convenient to work it for periods of 49 hours, 40 minutes at a stretch[1]), bringing it inboard to empty the balls and then putting it out again immediately. In a recent series of observations (the results of which are given below) 4 such periods were worked, and the residual drift over a period of 8 lunar days was thus determined.

### The Working up of the Results.

A convenient method for the working up of the results, due to Mr. T. Edser of the Ministry's Statistical Staff, has proved of great value, and Mr. Edser's memorandum is reproduced below: —

[1]) Longer periods are now frequently worked.

A Short Method for Determining the Residual Current from the Readings of the Drift Indicator (by T. Edser).

Form for resolution of residual current from readings by the Carruthers' meter.

Table No. 1.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Compartment Numbers.. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| No. of Balls ..... | .. | .. | .. | .. | .. | .. | .. | .. |
| Compartment Numbers.. | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| No. of Balls ..... | .. | .. | .. | .. | .. | .. | .. | .. |
| Key Letters ..... | A | B | C | D | E | F | G | H |
| Top line less middle line. | .. | .. | .. | .. | .. | .. | .. | .. |

Table No. 2.

| Products + | Products − | Key | No. of Units | Factor | No. of Units | Key | Products + | Products − |
|---|---|---|---|---|---|---|---|---|
| .. | .. | A | .. | 1.00 | .. | E | .. | .. |
| .. | .. | B — H | .. | .92 | .. | F + D | .. | .. |
| .. | .. | C — G | .. | .71 | .. | G + C | .. | .. |
| .. | .. | D — F | .. | .38 | .. | H + B | .. | .. |
| .. | .. | Components of vector of residual current. | | | | | .. | .. |

N = if positive = W.
S = if negative = E.

From traverse Table the components give a vector of .....
in direction .....
Factor for conversion of vector into miles per day .....
Residual Current = .....miles per day in direction .....

In the top line of the 1st table are entered the numbers of balls that have fallen in the westerly compartment commencing with the one whose axis points N as number 1, NNW as 2, NW as 3, etc., to SSW as 8. The second line commences with S as number 9, SSE as 10, SE as 11, etc., to NNE as 16. The figures in the second line are then subtracted from those in the 1st line, and the result (either + or —) entered in the spaces immediately below in the 3rd line. Thus in the space headed "A" is inserted the result of subtracting the figures under 9 from that under 1, etc.

In the second table under the headings "No. of Units" are entered the results of the operations indicated in the columns marked "Key",

e. g., in the left hand no. of units column the 1st space is filled up by the figure from space A in the 1st table, the second space by the result of subtracting the figure under H from that under B etc. The products of the no. of units by the factor are then entered in the appropriate places under the products headings, the entries being made in the same direction as the no. of units. The products are combined and the results give the component of the resultant vector, that to the left being the NS component, and that to the right the EW component.

A positive component on the left indicating a Northerly direction.
A positive component on the right indicating a Westerly direction.
A negative component on the left indicating a Southerly direction.
A negative component on the right indicating an Easterly direction.

The resolution of the components can best be effected by a traverse table and the application of the factor for the meter will convert the vector so found into miles.

The factors given are the Sines of 90°, $67^1/_2$°, 45° and $22^1/_2$° and the number of places used must be adjusted to the value of the record, thus for observations spread over only a few tides it might be sufficient to use only the corrected first decimal of the factor (1.0, 0.9, 0.7 and 0.4) whereas for observations extending over long periods it would be preferable to take 3 or even more places into account.

A justification of the method may be advisable. The problem resolves itself into compounding a series of radius vectors into one, and may be effected by combining together the NS and EW components of each vector. If, however, the number of shot or units in certain compartments can be eliminated by combination with others, the work is materially decreased. It is at once obvious that a positive number in one compartment is equal to a negative in its diametrically opposite one, so that the number of compartments can be reduced at once to half. This is done in table 1 giving the series A to H.

Consider A. The vector corresponding to these units is in direction NS and the factor of its component NS is + Sin 90° = + 1 and of its component EW is + Cos 90° = 0. Hence in the second table, A appears only on the left side of table 2.

Similarly E has factors + Sin 0° = 0, and + Cos 0° = + 1.0 and appears only on the right side.

B is in direction NNW-SSE with factors + Sin $67^1/_2$°, and + Cos $67^1/_2$°
H is in direction SSW-NNE with factors — Sin $67^1/_2$°, and + Cos $67^1/_2$°

therefore the NS combined component
is the product of ..... (B—H) and Sin $67^1/_2°$ = (B—H) 0.92
and the EW combined component is
the product of ..... (B + H) and Cos $67^1/_2°$ = (B + H) 0.38
Similarly:—
D is in direction WNW-ESE with factors of..... +Sin $22^1/_2°$, and +Cos $22^1/_2°$
F is in direction WSW-ENE with factors of..... —Sin $22^1/_2°$, and +Cos $22^1/_2°$
therefore NS combined component
= (D — F) Sin $22^1/_2°$ = (D— F) 0.38
EW combined component = (D + F) Cos $22^1/_2°$ = (D + F) 0.92
C is in direction NW-SE with factors of +Sin 45°, and +Cos 45°
G is in direction SW-NE with factors of —Sin 45°, and +Cos 45°
therefore NS combined component
= (C — G) Sin 45° = (C— G) 0.71
EW combined component = (C + G) Sin 45° = (C + G) 0.71

These combinations if suitably arranged will then appear as in the second table.

**Sample Results Obtained** (by J. N. C.)

The observer has a supply of calculation forms of the type suggested by Mr. Edser. Slight differences in the arrangement of the columns have been made since the above memorandum was written, as will be seen from the sample calculation given below. When the balls dropped during an observation have been counted, the residual current can be calculated with great ease.

The Lowestoft Fisheries Laboratory of the Ministry of Agriculture and Fisheries is maintaining two Drift Indicators in continual use on the Varne and Smith's Knoll Lightvessels respectively. A further instrument is available for use from the Ministry's Research Vessel, S. T. "George Bligh". The lightvessel observations are the outcome of a resolution passed by the Hydrographical Committee of the International Council at its meeting in Copenhagen in September 1924. The underlying idea is that it may be possible to "keep an eye" on the variations in the water movements, and it is further hoped (and experience shows this to have been realised) to glean information on the effect of winds blowing from different quarters.

In conclusion the following specimen results may be cited:—

A V. 65

MINISTRY OF AGRICULTURE AND FISHERIES.

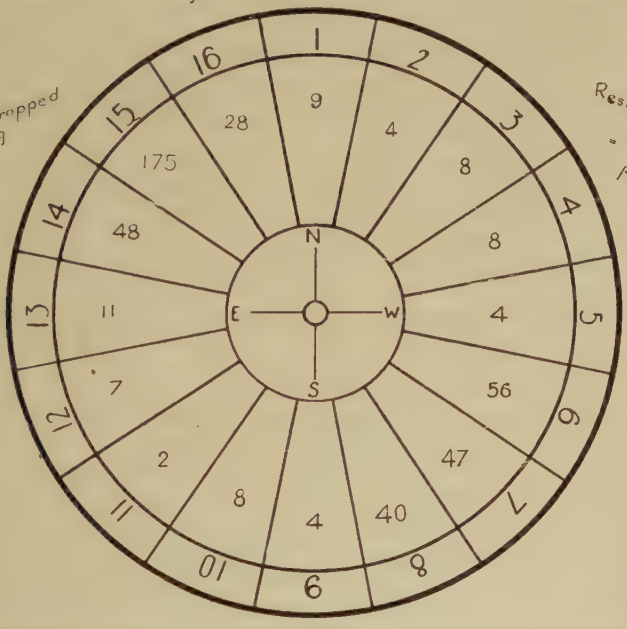
# DRIFT INDICATOR OBSERVATIONS.

Place of Observation :— Varne Lightvessel (between Folkestone & Boulogne)

Names of Observers :— W E White and A. Washburne

Depth Worked :— 6 fathoms

459 balls dropped representing 16.4 miles




Residual Current = 4.0 miles per Lunar Day towards N. 30° E true.

(The numbers of balls found in the various compartments of the Instrument are to be entered in the corresponding places in the above figure.)

| | DATE | HOUR |
|---|---|---|
| Time of commencement of the observations ... ... ... | 26 · 8 · 25 | 6 · 50 am |
| Time of cessation of the observations ... ... ... .. | 27 · 8 · 25 | 7 · 40 am |
| Duration of the observations ... .. ... ...* | | 24 hours. 50 mins |

State of the Tides (*i.e.* "Springs," "Neaps") :— Neaps

State of the Moon (*i.e.* "Full," "New," etc.) :— Seven days since New Moon

REMARKS (as to any apparent defects in the working of the instrument) :—

A. V. 65

# MINISTRY OF AGRICULTURE AND FISHERIES.

## FORMS FOR RESOLUTION OF RESIDUAL CURRENTS FROM DRIFT. INDICATOR READINGS.

Year: 1925

Place of Observation: Varne Lightvessel

Observer(s): W. E. White and A. Washburne

Period of Observation: 6-50 am. 26-8-25 to 7-40 am. 27-8-25

Duration of Observations: 24 hours 50 minutes

**Table No. 1.**

| Compartment Numbers. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. |
|---|---|---|---|---|---|---|---|---|
| No. of Balls ——— (*a*). | 9 | 4 | 8 | 8 | 4 | 56 | 47 | 40 |
| No. of Balls ——— (*b*). | 4 | 8 | 2 | 7 | 11 | 48 | 175 | 28 |
| Compartment Numbers. | 9 | 10 | 11. | 12. | 13. | 14. | 15. | 16. |
| Key Letters. | A. | B. | C | D. | E | F. | G. | H |
| Line (*a*) less line (*b*). | 5 | -4 | 6 | 1 | -7 | 8 | -128 | 12 |

**Table No. 2.**

| PRODUCTS. + | PRODUCTS. − | KEY. | No. of Units. | FACTOR | No. of Units. | KEY. | PRODUCTS + | PRODUCTS − |
|---|---|---|---|---|---|---|---|---|
| 5·00 | | A | 5 | 1.00 | -7 | E. | | 7·00 |
| | 14·72 | B—H. | -16 | .92 | 9 | F+D. | 8·28 | |
| 95·14 | | C—G. | 134 | .71 | -122 | G+C. | | 86·62 |
| | 2·66 | D—F. | -7 | .38 | 8 | H+B. | 3·04 | |
| 100·14 | 17·38 | | | Sums of Products. | | | 11·32 | 93·62 |
| + 82·76 | | | | | | | − 82·30 | |

Components of Vector of Residual Current:—

82·76 N. - if positive - W.

S. - if negative - E. 82·30

From Traverse Tables the components give a vector of 117

in direction N. 45° E mag.

Factor for conversion into miles: + 29

Total Water Movement throughout period concerned = ——— miles towards ———

Residual Current: = 4·0 miles per ~~day~~ lunar day

in direction N. 30° E true.

A V.65

## Wind and Sea Particulars during the time of the Observations.

MONTH:- August 1925

| DATE. | HOUR. | STRENGTH. | DIRECTION. | SEA. |
|---|---|---|---|---|
| | 3 a.m. | | | |
| | 6 a.m. | | | |
| 26th | 9 a.m. | 3 | WSW | 4 |
| | Noon | 4 | SW | 5 |
| | 3 p.m. | 4 | WSW | 5 |
| | 6 p.m. | 4 | WSW | 5 |
| | 9 p.m. | 4 | W | 5 |
| | Mid. Nt. | 4 | WSW | 5 |
| 27th | 3 a.m. | 4 | WSW | 5 |
| | 6 a.m. | 4 | WSW | 5 |
| | 9 a.m. | | | |
| | Noon | | | |

B

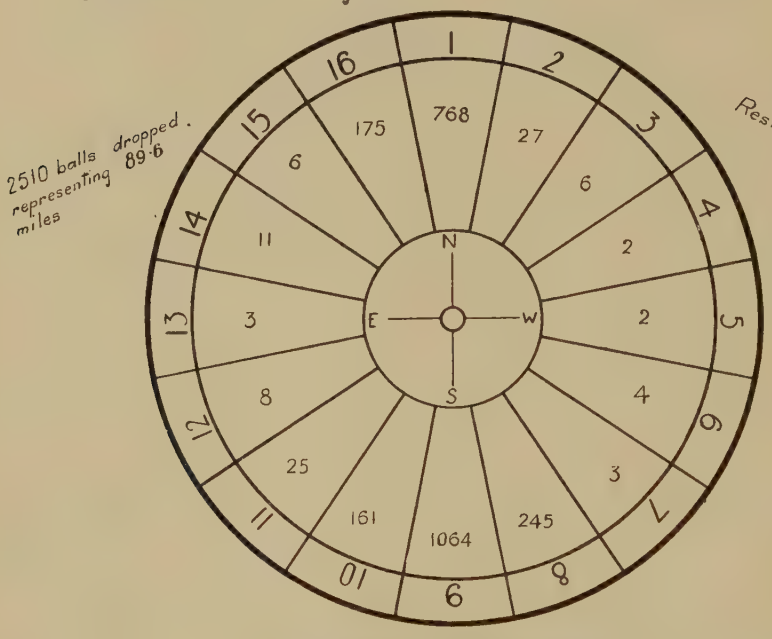
MINISTRY OF AGRICULTURE AND FISHERIES.

# DRIFT INDICATOR OBSERVATIONS.

Place of Observation :— Smiths Knoll Lightvessel {52° 43′ N. / 2° 17′ E.

Names of Observers :— H. Critten and W. J. East.

Depth Worked :— 17½ fathoms




2510 balls dropped. representing 89·6 miles

Residual Current

·17·8 miles towards S. 21° E. True

= 3·6 miles per Lunar Day.

(The numbers of balls found in the various compartments of the Instrument are to be entered in the corresponding places in the above figure.)

| | DATE. | HOUR. |
|---|---|---|
| Time of commencement of the observations ... ... ... | 12 · 9 · 25 | 11 · 0 am. |
| Time of cessation of the observations ... ... ... ... | 17 · 9 · 25 | 3 · 50 pm. |
| Duration of the observations ... ... ... ...* | 5 Lunar Days, 124 hours, 10 mins. | |

State of the Tides (*i.e.* "Springs," "Neaps") :—

State of the Moon (*i.e.* "Full," "New," etc.) :—

REMARKS (as to any apparent defects in the working of the instrument) :—

C

Cumulative Record over a period of 8 Lunar Days

MINISTRY OF AGRICULTURE AND FISHERIES.

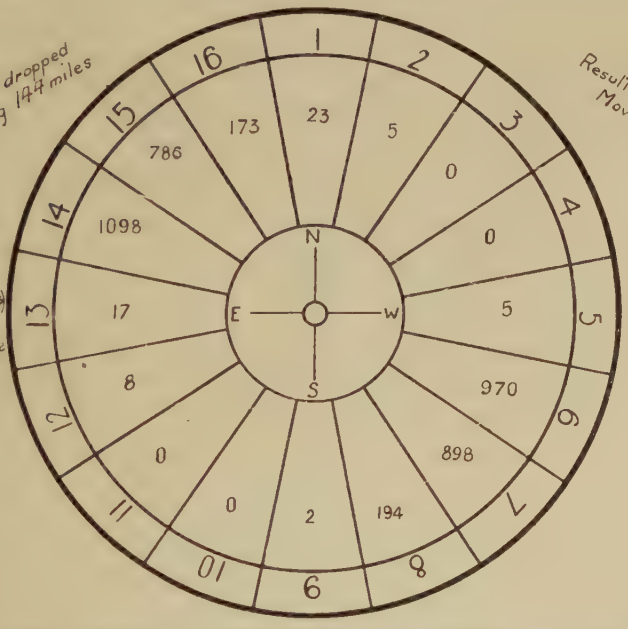
# DRIFT INDICATOR OBSERVATIONS.

Place of Observation :— Varne Lightvessel

Names of Observers :— W. E. White and A. Washburne

Depth Worked :— 6 fathoms

4179 balls dropped representing 144 miles




Resultant Water Movement

= 1·9 miles S 75° E True

= ¼ mile per Lunar Day.

Residual Wind throughout the period (66 observations) = 3·1 m.p.h. N. 64° W True

(The numbers of balls found in the various compartments of the Instrument are to be entered in the corresponding places in the above figure.)

| | DATE. | HOUR |
|---|---|---|
| Time of commencement of the observations ... ... .. | 10 - 9 - 25 | 8 - 0 am |
| Time of cessation of the observations ... ... ... .. | 18 - 9 - 25 | 3 - 0 pm |
| Duration of the observations ... ... ... ...* | 8 Lunar Days ~~hours~~. | |

State of the Tides (*i.e.* "Springs," "Neaps") :—

State of the Moon (*i.e.* "Full," "New," etc.) :—

REMARKS (as to any apparent defects in the working of the instrument) :—

(A) being the result of an observation made at the Varne Lightvessel in Dover Straits.

In this case the actual recording form is reproduced, and on it are superscribed the strength and direction of the residual current. The reverse of the form is also reproduced to show what records of wind and sea are kept by the observers and, in addition, the calculation form is reproduced.

(B) being the massed result of a series of observations made on the Smith's Knoll Lightvessel (about 30 miles NE from Great Yarmouth).

(C) being the massed result of a series of observations made on the Varne Lightvessel. This result embodies the records from 4 sets of observations each lasting 2 lunar days; it is of considerable interest by reason of the fact that the winds at the time were such as might be expected to oppose the entry of the Channel current into the North Sea. The residual wind for the whole period is seen to have been NW'ly and the residual current is merely of the order of 1.9 miles setting on to the French coast.

Note.

It has been the practice to supply lightvessel officers who carry out the observations with a memorandum of instructions. Copies of this will be supplied on request.

## Addendum.

Since this paper was written, experience gained in the use of the instrument has enabled many mechanical improvements to be made; notably the device for preventing jamming of the balls has been improved. An interesting development has been the construction of a compass system made of vulcanite tubing; the magnetised rods are merely placed in the tubes which are then filled with thick oil and conveniently sealed at the ends by means of screw-in plugs.

A long series of records (frequently lasting three lunar days each) is now ready for publication.

# On the Remarkable Quantities of Haddock in the Belt Sea during the Winter of 1925-26, and Causes leading to the same

by

Dr. **A. C. Johansen.**

In the Belt Sea a haddock fishery of unique extent was carried on during the past winter[1]). In the autumn of 1925, several remarkably large catches were made in this water by Danish and German vessels, and by January of the present year, the fishery had attained considerable dimensions. As the news spread, a number of fishermen from other parts were attracted to the spot, and by the middle of February, when the fishery was at its height, over a hundred cutters, besides many smaller craft, were working there. Most of these cutters were from Esbjerg, some were from Skagen, Lemvig, and other parts of Denmark, a few being from Sweden. The quantity taken per cutter and per fishing day often amounted to 2000—4000 kilos of haddock, besides numbers of cod.

Most of the haddock were taken in the channel between the north-west point of Ærø and Als, and in the Little Belt outside Aabenraa Fjord; also in the waters between Als and Fehmarn. Haddock were likewise found in considerable quantities in other parts of the Belt Sea, as for instance in the northern part of the Little Belt, in the Great Belt, and in the Bay of Lübeck to within the neighbourhood of Warnemünde.

The Danish fishermen worked mainly with the haddock seine, the Germans chiefly with the Kurre (a small otter trawl made higher and longer than the type generally used for flatfish so as to be better suited for the capture of haddock).

Statistics for the yield of the haddock fishery in the Belt Sea during the past winter have not yet been procured, but the catch probably

[1]) The Belt Sea is here taken as including the waters around Samsø, the Great Belt and Little Belt, with the Western Baltic from the shores of South Jutland to the line Gedser—Darsserort (see Fig. 1).

Fig. 1. Chart of the Kattegat and Belt Sea.

amounted to somewhere between $^3/_4$ and 1 million kilos. The value of the haddock landed in South Jutland in January and February 1926 has been roughly estimated by the Fishery authorities in Denmark at abt. 230,000 Kroner[1]). Reckoning the price as 50 Øre per kilo, this would give 460,000 Kilos. The yield of the German haddock fishery in the Belt Sea from October 1925 to February 1926 is estimated by Dr. Heidrich, of Hamburg, at 160,000 Kilos[2]).

Comparing the yield of the Danish haddock fishery in the Belt Sea during the first two months of the present year, with the yield in previous years, as noted in the Fiskeri-Beretning, we find the following figures:

Table 1. Yield of the Danish Haddock Fishery in the Belt Sea. Kilogrammes.

| | |
|---|---|
| 1909 ..... | 0 |
| 1910 ..... | 0 |
| 1911 ..... | 250 |
| 1912 ..... | 0 |
| 1913 ..... | 15550 |
| 1914 ..... | 2700 |
| 1915 ..... | 0 |
| 1916 ..... | 5100 |
| 1917 ..... | 0 |
| 1918 ..... | 0 |
| 1919 ..... | 0 |
| 1920 ..... | 0 |
| 1921 ..... | 0 |
| 1922 ..... | 0 |
| 1923 ..... | 200 |
| 1924 ..... | 270 |
| 1925 ..... | 59000[3]) |
| 1926 ..... | c. 500000 (January and February alone) |

From this it will be seen that the yield of the haddock fishery in the Belt Sea during previous years was altogether insignificant in comparison with that of the past season. — True, it should be borne in mind that the haddock-seine has not previously been employed in the Belt Sea. But line fishery for cod has been carried on there from the very earliest times, and if there had been any great abundance of haddock

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[1]) From information kindly furnished by Fiskeridirektør Mortensen.

[2]) Herbert Heidrich: "Der Schellfischfang in der westlichen Ostsee". Der Fischerbote 1. April 1926.

[3]) of which 28000 kilos during the first months of the year and 31000 kilos in the last months of the year.

at any time, it would certainly have shown itself in the yield of the line fishery. Moreover, haddock are also taken in the ordinary seine as used for plaice, as well as in the otter trawl and gill nets. It was evidently the great abundance of haddock in the Belt Sea during the past season which led to the use of the haddock seine in those waters.

The above data clearly show that there was, in the winter of 1925—26, a remarkable abundance of haddock in the Belt Sea. And we naturally ask, what was the cause of this abundance, and what are the prospects for this fishery in the future?

The haddock is a pronounced salt water fish, not spawning to any great extent in water of less than 34 ‰ salinity. As a rule, this 34 ‰ water extends in to the boundary area between the Skagerak and Kattegat during the spawning season of the haddock, in early spring, and we find here also a rather sharply defined boundary for the spawning grounds of the haddock.

In certain years, however, the 34 ‰ water penetrates to a great extent into the Kattegat, and the boundary of the haddock spawning ground then shifts further southward, while the larvæ are also carried in with the salt bottom current from the Skagerak.

As I have previously pointed out[1]) there was, in the spring of 1923, an abnormally strong inflow, from the Skagerak to the Kattegat, of a mixture of North Sea and Atlantic water. This was shown by the marked rise in salinity of the lower water layers in these parts throughout a large portion of the spring and early summer, as for instance:

At Skagens Rev Lightship, from early Feb. to abt. 1 May (abt. 0—1 ‰ above normal)
- Læsø Trindel — mid. Feb. to early May (0.5—1 ‰ above normal)
- Anholt Knob — early March—mid May (1—2 ‰ above normal)
- Schultz' Grund — abt. 9 March—19 June (1.5—2 ‰ above norm.)
- Halskov Rev — 13 March—29 June (4—6 ‰ above normal)

The temperature of the inflowing salter water was abt. 1—2° C. above normal.

In the western part of the Baltic also, observations made at the stations of the research vessel "Dana" on the 20th and 21st of April 1923 revealed a considerably higher salinity of the bottom water than normal, as will be seen from the following:

---

[1]) Fiskeri-Beretning for Aaret 1923, Copenhagen 1924 p. 108, and A. C. Johansen: On the Influence of the Currents upon the frequency of the Mackerel in the Kattegat and adjacent parts of the Skagerak. Medd. Komm. f. Havunders. Serie: Fiskeri Bd. VII No. 8 Copenhagen 1925.

| | depth | salinity | normal sal. |
|---|---|---|---|
| S.W. of Langeland | 30 m | 25.46 ‰ | 22 ‰ |
| S.E. — | 23 | 27.74 | 21 |
| N. of Fehmarn | 28 | 25.35 | 21 |
| E. — | 22 | 22.50 | 19 |
| Kadetrenden | 25 | 20.55 | 16 |
| S. of Møen | 21 | 18.82 | 13 |

The marked inflow of salt and warm water was also evident from the composition of the plankton in the water. The plankton found in the Kattegat and the Belt Sea contained a series of organisms not generally found there, but belonging to the open sea. The siphonophores for instance, were represented by two species, *Physophora hydrostatica* and *Galeolaria truncata*, which belong to the warm Atlantic water, and with two other species belonging to the northern fauna. Larvæ of the coalfish (*Gadus virens*) also were found, both in the Kattegat and in the northern part of the Sound, while its larvæ are not normally met with farther towards the Baltic than the Skagerak. Other species, including larvæ of the haddock, were of far more frequent occurrence than normally, and were also found farther up in the Baltic waters than usual.

The catch of haddock larvæ from the "Dana" in the spring of 1923 is illustrated by the chart Fig. 2, showing the number taken per 30 minutes' haul with a ring trawl of 2 m. diameter. (In certain cases, the Petersen young-fish trawl of similar opening was used instead of the ring trawl).

During the months of April, May and June, there were, as shown in Fig. 2, numerous haddock larvæ found in all parts of the Kattegat, some of the larvæ being so small that they must be presumed to have developed in the Kattegat itself. But a great number of the haddock larvæ found in the Kattegat must plainly have been carried in from the Skagerak with the salt bottom current, which carried many of them farther on again into the Belt Sea. The Kattegat and Belt Sea were thus stocked to an unusual degree with haddock larvæ. According to the investigations of Harold Thompson,[1]) the year 1923 was a favourable one for development of the haddock fry in the North Sea, and the same was evidently the case as regards the Skagerak. It is not surprising then, that the strong current from the North Sea and Skagerak should carry numbers of haddock larvæ into the Kattegat and Belt Sea; probably also, a number of adolescent haddock entered these waters at the same time. At the close of May and beginning of June 1923 I was able to show, by fishing experiments with the ring trawl from the research vessel "Dana", that the haddock larvæ had passed down right through

[1]) Harold Thompson: Problems in Haddock Biology. I. Fisheries, Scotland. Sci. Invest. 1922. 2, V. (May 1923).

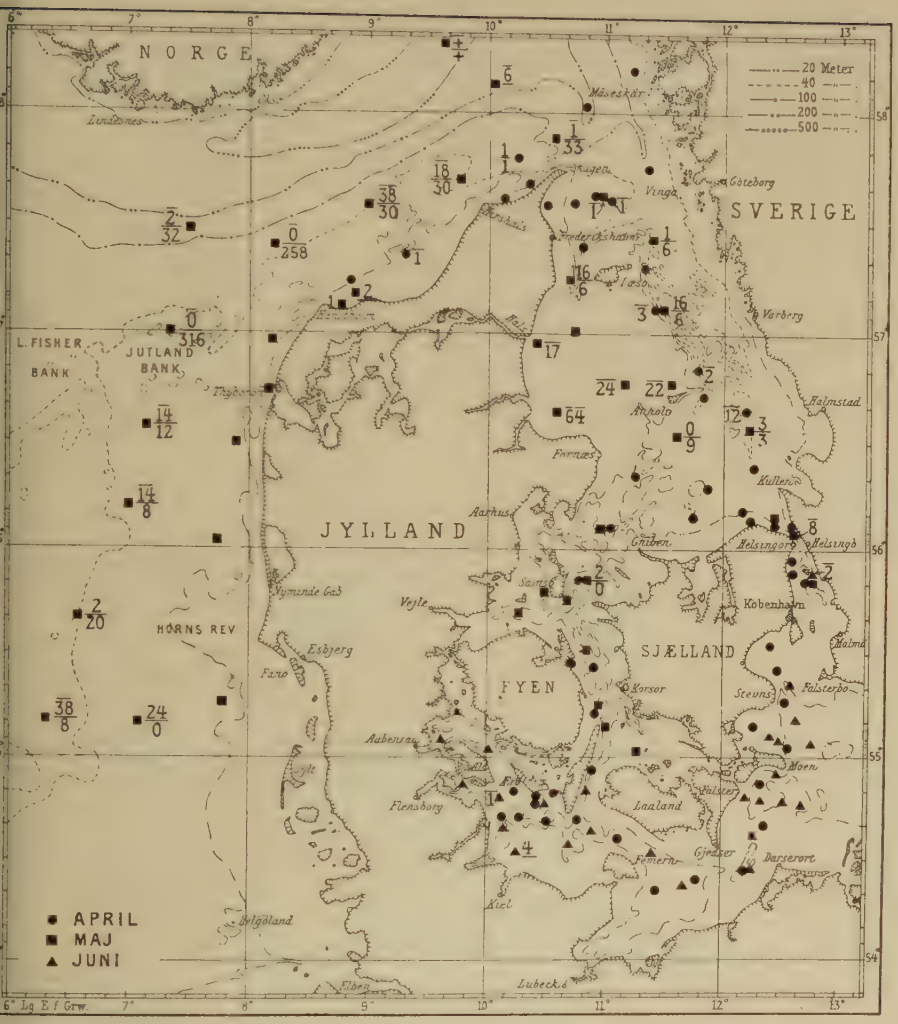


Fig. 2. Catch of Haddock larvae per 30 minutes' haul with ring trawl and young fish trawl from the "Dana" in April, May and June of 1923.
The figures above and below the lines state the number of larvae caught in the upper layers (down to 12 metres) and in the lower layers, respectively.
For the North Sea and Skagerak a line above the upper figure indicates that the hauls are taken at depths between 16 and 28 metres.

the Great Belt into the western part of the Baltic[1]). These haddock larvæ were of the following lengths:

[1]) Fiskeri-Beretning for Aaret 1923 p. 108.

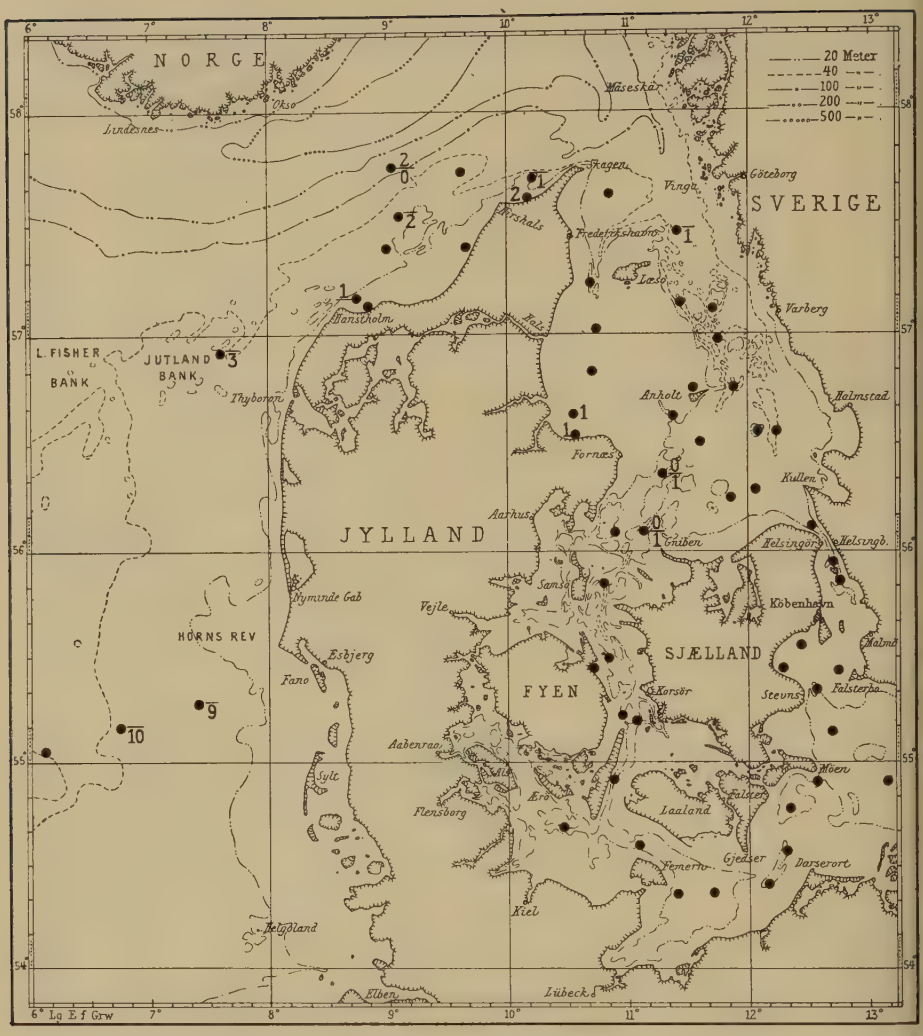


Fig. 3. Catch of Haddock larvae per 30 minutes' haul with ring trawl and young fish trawl from the "Dana" in April of 1925. For further explanation see Fig. 2.

St. 3060 30-5-25 E. of Samsö 2 spec. 9,19 mm.
- 3070 1-6-23 N.N.E. of Bülk Light 4 spec. 15, 16, 18, 20 mm.
- 3076 4-6-23 S.E. of Gl. Pöl Light 1 spec. 18 mm.

At the two first-mentioned stations, the larvæ were taken in the upper water layers, where the salinity was 15—18 $^0/_{00}$.

It will be seen then, that none of these haddock larvæ could have been recently hatched (the length of the newly hatched stages is abt. 4 mm). Most of them must presumably have been abt. 2 months old.

At the end of April, we made fishing experiments with the ring trawl at 17 different stations in the Belt Sea, and no haddock larvæ were then taken, though there were at that time numerous tiny haddock larvæ in the North Sea, Skagerak and eastern Kattegat. It seems evident then, that we have here to deal with larvæ not spawned in the Belt Sea itself, but carried in with the salt bottom current.

Most of the larvæ taken in the Kattegat in April—May 1923 were found, at any rate during the day, in the lower water layers, where the general trend of the current is inwards (or directed towards the Baltic), and it must be presumed that a great part of the larvæ from the Kattegat drifted down into the Belts and the western Baltic after the ring trawl fishery there was at an end.

Under ordinary circumstances, only very few haddock larvæ are found in the Kattegat. Fig. 3 shows the catch from the "Dana" with the ring trawl in the spring of 1925, when the salinity of the lower water layers was normal. The enormous difference in the catch of haddock larvæ in the two years is here conspicuously evident.

The abnormal occurrence of haddock larvæ in the Belt Sea was thus noted in the investigations made from the "Dana" at the end of May and beginning of June 1923, and in the late summer and autumn of 1923, young bottom stages of haddock, evidently spawned the same year, were observed at several places in the Belt Sea[1]). Dr. Petersen for instance, found, in the late summer, quite a number of haddock of about two inches length at certain places in the Belt Sea, e. g. in the Smaaland Bay down to Fæmø and in the Belts down as far as Als, while Professor Steyer, of Lübeck, informed me that German fishermen had been surprised to find, in October 1923, numerous small haddock of abt. 15 cm. length in Eckernförde Fjord. According to Steyer, also, some haddock, length not stated, were caught in the Bay of Lübeck, where haddock are not generally found.

In the winter of 1924—25, when the haddock in the Belt Sea had grown somewhat, they became the object of increased attention on the part of the fishermen, and in the Bay of Aarhus, a special fishery was carried on for these fish, with a fine-meshed snurrevaad. In several of the South Jutland fjords, they were captured in considerable numbers in seines, and at some places also in pound nets together with the herring. With regard to their size, we have *inter alia* the following data:

---

[1]) as early as the 24th of June 1923 I found, in the deep channel of the Sound off Landskrona, some few haddock of 4—4.5 cm. length, at the transition between pelagic and bottom stage.

In the Bay of Aarhus, the haddock taken in snurrevaad in January 1925 were 25—38 cm long, most of them, 30—35 cm.

In the South Jutland waters, Aabenraa Fjord, Alssund, Vemmingbund etc. most of the haddock captured were, according to information from the fishery authorities, between 30—35 cm long, and several smaller were observed, down to abt. 25 cm. Magister A. Strubberg examined a sample of such haddock taken by purse seine in Vemmingbund, on the 18. April 1925, and found the length varied from 25 to 37 cm, with an average of 29 cm.

Dr. E. Fischer, of Berlin, measured a sample of 121 haddock taken at Travemünde in April 1925. The length varied from 25—38 cm, average abt. 31 cm[1]).

Thus the size of the haddock was rather uniform in the various places of the Belt Sea in the first months of the year 1925, and according to their size and the previous observations regarding the occurrence of the haddock larvæ in the Belt Sea in May—June 1923 and the occurrence of young bottom stages in late summer and autumn 1923 it would seem probable that the first in question were the larger specimens of the year class of 1923, which as larvæ were transported into the Belt Sea with the great inflow of salt water in the spring of 1923. In order to obtain information as to the growth of the haddock in the Belt Sea during their two first years of life, we calculated the length at the close of the first and second year of life from observation of the breadth of the growth rings in the scales of 78 three-year-old haddock taken in Aabenraa Fjord on the 30th of January 1926; see Table 2.

The two-year-old haddock in the sample from Aabenraa were then, it is true, according to this calculation, somewhat smaller than the majority of the fish taken by the fishery in the Belt Sea during the winter of 1925—26. Still, bearing in mind the fact that fishery for small haddock practically speaking always yields a disproportionately high percentage of the larger sizes, we can hardly doubt but that the great majority of the haddock taken during the winter of 1925—26 belonged to the 1923 year-class.

The great catches of haddock in the Belt Sea in the winter of 1925—26 were thus not altogether unannounced, and as the fish were somewhat larger than those of the winter 1924—25, it would seem natural to suppose that they were still from the 1923 year-class.

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[1]) E. Fischer: Das Auftreten von Schellfischen in der Ostsee. Mitteilungen des deutschen Seefischerei-Vereins. Jan.-Febr. 1926.

Table 2. Length of 78 haddock taken in Aabenraa Fjord 30th January 1926 at the close of their:

| cm | First year | Second year | Third year |
|---|---|---|---|
| 11 | 2 | .. | .. |
| 12 | 1 | .. | .. |
| 13 | 6 | .. | .. |
| 14 | 8 | .. | .. |
| 15 | 4 | .. | .. |
| 16 | 12 | .. | . |
| 17 | 12 | .. | .. |
| 18 | 15 | .. | .. |
| 19 | 7 | .. | .. |
| 20 | 5 | 1 | .. |
| 21 | 4 | 2 | .. |
| 22 | 1 | 1 | .. |
| 23 | 1 | 4 | .. |
| 24 | .. | 5 | .. |
| 25 | .. | 5 | .. |
| 26 | .. | 13 | .. |
| 27 | .. | 10 | .. |
| 28 | .. | 9 | .. |
| 29 | .. | 6 | 1 |
| 30 | .. | 11 | .. |
| 31 | .. | 2 | .. |
| 32 | .. | 1 | 4 |
| 33 | .. | 2 | 6 |
| 34 | .. | 5 | 10 |
| 35 | .. | .. | 6 |
| 36 | .. | 1 | 7 |
| 37 | .. | .. | 10 |
| 38 | .. | .. | 6 |
| 39 | .. | .. | 9 |
| 40 | .. | .. | 6 |
| 41 | .. | .. | 2 |
| 42 | .. | .. | 4 |
| 43 | .. | .. | .. |
| 44 | .. | .. | 2 |
| 45 | .. | .. | 2 |
| 46 | .. | .. | 2 |
| 47 | .. | .. | .. |
| 48 | .. | .. | 1 |
| No. | 78 | 78 | 78 |
| Average length in cm. | 16.8 + 0.2 | 27.6 + 0.4 | 37.4 + 0.5 |

Measurements of samples of haddock taken at different places gave the following result:

Table 3. Total length of haddock from waters east of S. Jutland. January—February 1926.

| Locality: | Aabenraa Fjord | Between Als and Ærø | Landed at Sønderborg | Landed at Sønderborg | |
|---|---|---|---|---|---|
| Date | 30. Jan. | abt. 8. Febr. | abt. 13. Febr. | abt. 15. Febr. | Total |
| cm | No. | No. | No. | No. | |
| 18 | .. | .. | .. | 1 | 1 |
| | .. | .. | .. | .. | .. |
| | .. | .. | .. | .. | .. |
| 28 | .. | .. | .. | 1 | 1 |
| 29 | 1 | .. | .. | .. | 1 |
| 30 | .. | 1 | .. | .. | 1 |
| 31 | .. | 1 | .. | .. | 1 |
| 32 | 4 | 2 | .. | 1 | 7 |
| 33 | 6 | 3 | .. | 3 | 12 |
| 34 | 10 | 10 | 1 | 8 | 29 |
| 35 | 6 | 13 | .. | 9 | 28 |
| 36 | 7 | 26 | 3 | 8 | 44 |
| 37 | 11 | 16 | 2 | 8 | 37 |
| 38 | 6 | 21 | 2 | 2 | 31 |
| 39 | 10 | 12 | 2 | 3 | 27 |
| 40 | 6 | 16 | 4 | 2 | 28 |
| 41 | 2 | 13 | 3 | 3 | 21 |
| 42 | 4 | 4 | 4 | .. | 12 |
| 43 | .. | 3 | 3 | 2 | 8 |
| 44 | 2 | 2 | 3 | .. | 7 |
| 45 | 2 | 1 | 2 | .. | 5 |
| 46 | 2 | .. | .. | .. | 2 |
| 47 | .. | .. | .. | .. | .. |
| 48 | 1 | 1 | .. | .. | 2 |
| No. | 80 | 145 | 29 | 51 | 305 |

Age analyses of the 305 specimens noted in Table 3 gave the following result[1]):

| | year class 1925 | year class 1923 | year class 1922 | year class 1921 |
|---|---|---|---|---|
| No. of specimens | 1 | 301 | 2 | 1 |
| Length in cm. | 18 | 28—48[2]) | 43—44[3]) | 48[3]) |

Examination at the Danish Biological Station of 44 haddock measuring 33—48 cm, taken outside Hørup Hav, Als, abt. 8 Feb. showed that all belonged to the 1923 year-class[4]). Age analyses made by Heidrich with

[1]) Most of the age analyses were made by Magister Erik M. Poulsen.

[2]) Average length 37.6 + 0.5 cm.

[3]) Taken between Als and Ærø.

[4]) C. G. Joh. Petersen: Om det nye Kullerfiskeri i vore sydlige Farvande. Fiskeribladet 1. Marts 1926.

88 haddock taken in the western Baltic on the 26 Febr. and 2 March 1926 showed that 87 specimens of 27—51 cm length were of the 1923 year class, while a single individual of 56 cm belonged to the 1921 year class.

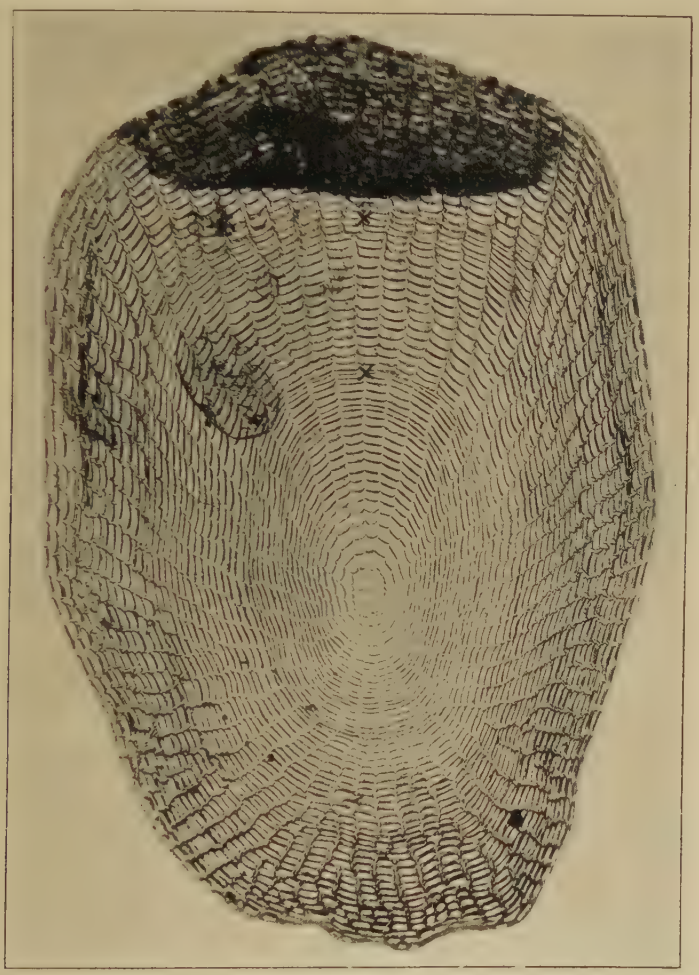

Fig. 4. Scale of Haddock of the II-Gr. (nearly 3 years old) male of 45 cm. length caught in Aabenraa Fjord, 30 January 1926.
The crosses are placed where the edge of the scale occurred at the end of the first and the second growth year.

According to information procured by the Danish Fishery Authorities, and kindly communicated by Fiskeridirektør Mortensen, there were, in addition to the "small" haddock of abt. 30—40 cm and the "medium" fish of abt. 40—50 cm, also a number of "large" haddock,

abt. 50—66 cm, in the catches; these however, never amounted to 10 % of the total weight of the yield, even during that part of the season when they were most numerous. It is beyond question that at any rate the largest of these must have been more than 3 years old. In the North Sea, according to HAROLD THOMPSON, haddock of 60—66 cm are between 5 and 10 years old or thereabout.

In the reports sent into the Danish Fishery Board there is no mention of any captures of specimens about 22—27 cm. total length; it is stated however, that some few specimens about 20 cm total length were caught, and these last evidently belonged to the 1925 year-class.

We can then, from the analyses made, safely conclude that abt. 99 % of the haddock landed from the Belt Sea during the winter of 1925—26 belonged to the 1923 year-class.

The one peculiar feature about the stock of haddock in the Belt Sea in the winter of 1925—26 was then, the fact that nearly all the fish belonged to a single year-class, viz. 1923, the 1924 year-class being practically speaking absent altogether. This argues most decidedly against the suggestion that the abundance of haddock in the Belt Sea should be due to an unusual invasion from the Skagerak and northern Kattegat in the winter of 1925—26, as the stock of haddock there was of entirely different composition. True, the 1923 year-class was richly represented in the catches from these waters, but the 1924 year-class was also very well represented among the "small" market fish. A single example will suffice to show this very plainly. Analysis of a sample of 104 selected small haddock of 24—37 cm length taken at Læsø Trindel 21 Febr. 1925 showed the following figures:

| | 1925 year class | 1924 year class | 1923 year class |
|---|---|---|---|
| No. of specimens | 1 | 97 | 6 |
| Length in cm. | 24 | 25—35 | 32—37 |

The "small haddock" from which the above sample was taken amounted to about half the catch at the locality in question. The analysis quoted thus gives an instance of the degree to which the 1924 year-class was represented in the catches from the northern Kattegat in the early part of 1926, in contrast to what we find in the Belt Sea.

There are however, also other features which militate against the suggestion that the three-year-old haddock predominating in the Belts in the winter of 1925—26 recent arrivals. We find for instance, that the genital organs in these three-year-old fish were, in January and February, far less developed than is normally the case at the season in question, among adult haddock in the North Sea and Skagerak. Out of a sample

of 80 specimens from Aabenraa Fjord from the end of January, 71 were due to spawn in the spring of 1926, but the eggs were quite small, only abt. 0.2—0.3 mm diameter, and the testes as yet but slightly swollen. It looked then, as if these fish would not spawn before April or May, whereas the haddock of the Skagerak have their main spawning season in March. It seems likely then, that these haddock had remained so long in the Belt Sea that the development of their genital organs had been distinctly affected by their stay there.

We find then, that the great haddock fishery in the Belt Sea during the winter of 1925—26 was due to exceptional circumstances. In the first place, an abnormally powerful inflow of water from the Skagerak to the Kattegat led to some degree of spawning there by the haddock, whereas normally, the Kattegat haddock migrate to the Skagerak or the North Sea to spawn. Furthermore, the strong bottom current carried haddock larvæ from the Skagerak to the Kattegat and from the Kattegat to the Belt Sea, this transport of larvæ being the more extensive because the year 1923 was a favourable survival year for the young haddock in the North Sea and the Skagerak. Then again, the winter movement of the haddock from the Skagerak to the Kattegat was doubtless in excess of the normal owing to the abnormally high salinity of the lower water layers in the Kattegat during November—December 1924. Possibly also, a not altogether inconsiderable number of small haddock of the 1923 year-class may at the same time have advanced from the Kattegat to the Belt Sea.

In view of the facts thus set forth, it must be admitted that future prospects for the haddock fishery in the Belt Sea are not bright. The extensive fishery was due to a combination of fortunate circumstances which will not often be repeated. But we are still without sufficient experience to judge how the great stock of haddock in the Belt Sea will behave[1]). Some small percentage of the haddock will not attain maturity in the present spring, and it is not unlikely that these may remain in the inner Danish waters until next spring. The main bulk of the three-year-old haddock in the Belt Sea however, attain maturity in the present spring, and it now becomes a question, whether these will emigrate to the Skagerak or North Sea to spawn, or remain in the Belt Sea throughout the summer. It is probable that the majority will emigrate, and the great decrease in the fishery which has been observed since the end of February suggests that this migration has already been

[1]) A considerable portion of the stock of haddock in the Belt Sea was probably caught during the winter of 1925—26, but hardly the main part.

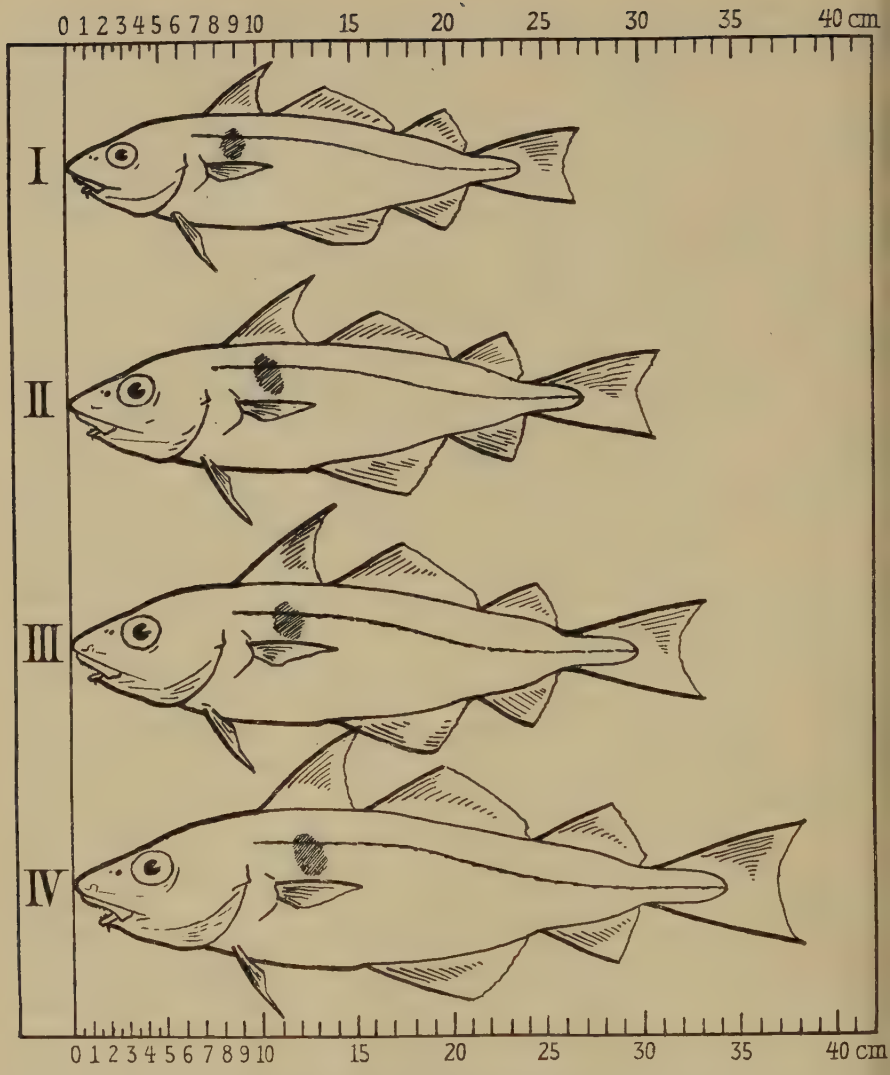


Fig. 5. Length of Haddock from various localities at the end of their third year:
I. Fladen after HAROLD THOMPSON.
II. Dogger Bank — — —
III. Jutland Bank — — —
IV. The Belt Sea

going on for some time past. But it is possible that not all the mature haddock will manage to find their way out from the numerous bays and creeks of the Belt Sea in the present spring, and we may now ask whether such relicts will be able to propagate in this water.

It seems likely that if any larvæ are developed at all, it will only be very few, and not sufficient to renew the large stock. We do not find, among haddock, special brackish water races, such as are known to exist among many other species of our fishes, like the herring, cod, plaice, flounder, turbot etc.

The haddock of the Belt Sea have, during their two first years of life, about the same growth as those of the North Sea but in their third year, they have grown much faster. The average length of the haddock in the Belt Sea at the close of their first year was as above noted, abt. 17 cm; at the close of the second year abt. 28 cm, and at the close of the third year abt. 38 cm. For purposes of comparison, the following figures are given (after HAROLD THOMPSON) for length of haddock from various localities in the North Sea at the close of their:

| | first year | second year | third year of life |
|---|---|---|---|
| Fladen | 17.5 | 23.5 | 27.0 cm |
| Dogger Bank | 17.5 | 26.0 | 31.0 |
| South-west Norway | 17.0 | 26.0 | 31.5 |
| Jutland Bank | 17.5 | 28.0 | 33.0 |

The rapid growth of the haddock in the Belt Sea shows that they have found here particularly favourable conditions of nourishment, and it might be imagined that haddock which have grown up in the Belt Sea would return to those waters after their spawning and possibly bring with them shoals of other haddock. This however again seems rather an optimistic view.

At certain periods in earlier times, a regular haddock fishery was carried on in the inner Danish waters. In the Sound, for instance, the line fishery for haddock north of Hveen did not cease until about 1886, dating back as far as tradition can reach among the fishermen of the Sound[1]). In the excellent work: "Danmarckis oc Norgis Fructbar-Herlighed" dating from 1665, the writer, ARENNT BERNTSEN, mentions the haddock as one of the important species in the Sealand fishery, together with herring, cod, flounder, eel and whiting. It is likely that in those periods when the haddock penetrated comparatively far into the inner Danish waters, there was also a relatively marked inflow of salt water from the Skagerak either during the spring or autumn.

It will be seen from Table 1 that in 1913, more haddock were taken in the Belt Sea than in any year between 1909—1924, but the yield

[1]) This fishery was carried on mainly during the months of May and June.

was still inconsiderable in comparison with that of the present year. We naturally ask then, whether there was, three years before, i. e. in 1910, also an unusually marked inflow of water from the Skagerak to the Kattegat. This was not the case, but going one year farther back, i. e. to 1909, we do find such a marked inflow of water. The size of the fish taken in 1913 is not known, but they were undoubtedly taken by line fishery, and it is likely then that they would on the average have been somewhat larger than those taken in the Belt Sea during the present year; it is not unreasonable, therefore, to suppose that they may have been four-year-old fish.

On the northern coasts of Sealand, and especially at the northern entrance to the Sound, there was, as in the Belt Sea, an unusually heavy haddock fishery in the winter of 1925—26, and some few haddock even penetrated right in as far as Drogden, which is an altogether unusual phenomenon. From October to December 1925, the yield of the haddock fishery from the fishing villages of the Sound amounted to abt. 114,000 kilos. During the first months of 1926, the fishery was continued, and the fishermen from Gilleleje, Hornbæk etc. brought in daily catches of 2—3000 kilos per boat. During the period 1909—24, the total yield of the haddock fishery in the Sound for all years together amounted to only 56,000 kilos.

We have thus witnessed an experiment made by Nature itself on a grand scale, showing that the haddock can thrive in the Belt Sea from the larval stage right up to the adult fish; and that the inner Danish waters offer, indeed, particularly favourable conditions for growth. It seems natural then to consider whether artificial fertilisation and hatching of haddock eggs, with subsequent liberation of the young fish in the Belt Sea might not prove a profitable undertaking. It is by no means impossible that it might. Preliminary experiments in regard to the hatching of haddock eggs, and the ability of the larvæ to survive transport etc. would perhaps yield information of importance in this respect.

# Reviews.

## Essay-Review.

### On Works concerning the Valuation of the Southern North Sea

by

C. G. Joh. Petersen. Ph. D., LL. D., D. Sc.

In 1914 I published in Rep. Dan. Biol. Station XXII a hypothetical chart of the animal communities of the North Sea, based exclusively upon fauna-lists in the literature at hand. In this chart an area along the coasts was shown as inhabited by a "*Macoma baltica*" community, while the rest of the Southern North Sea was designated as a "*Venus*" community, excepting only a small part of the central area which, with a query, was indicated as a "*Brissopsis*" community. As the method used of course could not give reliable results I was very glad to learn that the English Ministry of Agriculture and Fisheries in 1921 decided to start investigations with my "Grab" in the North Sea. In July 1921 the first attempt was made to find out, which animal communities really are to be found in the Southern North Sea, a series of bottom samples being taken from the research vessel "George Bligh" during its voyage from Lowestoft to Esbjerg. The assistant of the Danish Biological Station, Dr. H. Blegvad, accompanied the English naturalists during this voyage; he has in Proc. Zool. Soc. London, April 1922, given a short account of the results. He found 1) in the harbour of Lowestoft a "*Macoma*" community, 2) from the English coast outwards a poor "*Venus*" community, 3) following thereafter an "*Amphiura*" community, 4) nearer the coast of Jutland again a "*Venus*" community, and 5) at Horns Reef a community with "*Syndosmya alba*"; all these are communities which, though containing some few new species, exactly correspond to those found by us in the Kattegat at lesser depths; in deeper water several other communities are found in the Kattegat.

In 1923 the first Report on the "Grab" work carried out by F. M. Davis, of Lowestoft, during the years 1921—23 was published under the title of "Quantitative Studies on the Fauna of the Sea Bottom, Part I" (Ministry of Agriculture and Fisheries. Fishery Investigations Ser. II. Vol. VI. No. 2). It gives the results of an investigation of the Dogger Bank, which was found to be inhabited by a quantitatively very rich fauna; especially the two species *Spisula subtruncata* and *Mactra stultorum* occurred in big "patches" or "beds", some of these being 700 sq. miles in extension and containing a population of abt. 4,500 Milliards of young *Spisula*. Davis found the general fauna to agree with my "*Venus*" or "*Deep-Venus*"

community; only towards the edges, and in the deep water off it, it seemed gradually to change into my "*Echinocardium-Filiformis*" community.

During the years 1922—24 similar investigations were carried out by Dr. A. Hagmeier from the "Biologische Anstalt" of Heligoland (Berichte d. Deutschen wiss. Komm. f. Meeresforschung. N. F. Bd. I. 1919—23) between Esbjerg and the coast of Holland. He found the same communities as Blegvad; he could, however, based upon his much more extended investigations, give more detailed information on their geographical distribution and their contents, — for one thing on the occurrence of *Syndosmya alba* in the North Sea. He found this bivalve in numbers round Heligoland from the outer limit of the "*Macoma*" community, where a pure "*Syndosmya*" community, was found, to far out West of Heligoland in the "*Echinocardium-Filiformis*" community; also transitions between the "*Venus*" and the "*Echinocardium-Filiformis*" communities were found here, as could be expected in waters with evenly increasing depths where the transitions from one community to another must play a greater part than in the Kattegat. It is certainly possible to divide the communities in the North Sea into more subdivisions than we find it convenient in the Kattegat; how far one may go in this direction, becomes a question to settle for each separate area of investigation. But in the main lines the best agreement, as to the main communities, was found to exist between the shallower parts of the Kattegat and the South-eastern North Sea, excepting only with respect to *Syndosmya alba*. How this last named fact is to be understood, must for the present remain doubtful; these investigations still are in their beginning.

In 1925 No. 2 of the "Quantitative Studies on the Fauna of the Sea Bottom" by F. M. Davis was published (Min. Agr. Fish. Fishery Investigations Ser. II. Vol. VIII. No. 4). In this paper all the work carried out with the "Petersen Grab" during the years 1921—24 has been treated, but in another way than that used in his first paper. Thus Davis makes no attempt first of all to get a general view, accompanied by a chart, of the distribution of the different communities in the North Sea; he takes another way, trying to orientate himself by making the texture of the soil, the inorganic particles or at any rate the non-living material, the basis of the classification of the existing associations of animals. Although it may sometimes be possible by this method roughly to follow up the occurrences of the communities, still there will be so many exceptions from the rule, that the method seems to me to be very dangerous. If anyone intended, as I from the beginning did, to get knowledge as to which areas of a sea have identical faunas, his obvious course would have been to examine the animals themselves, and not to make a circuit, which is known to be impossible to employ with respect to several species, thus for instance absolutely not in the case of the "*Macoma*" community.

Davis refers to the fact that the characteristic of the communities of the Kattegat does not appear to be adequate to the whole of the North Sea; this is very probable, it is just the thing which has to be investigated. But if the Kattegat communities do not agree with the conditions in the North Sea, then some other communities must be set up on the basis of the new investigations. Davis himself says page 16 that "communities do undoubtedly exist".

I understand, however, very well the difficulties connected with these investigations in the North Sea in many places, for the fauna is often poor as compared with that of the Kattegat, and the bottom conditions are often "patchy" or "a mosaic of soils"; furthermore so few characteristic communities are to be found in the Southern North Sea that we easily may lose the general view of the conditions there, with the many gradual transitions between the communities. But I believe that we still more will lose the general view if we do not stick to the living animals but proceed to set up some different sorts of "soils", in which the different communities then have to appear. I understand quite well that Davis wishes to remove any subjective estimate from these investigations, and it may, especially where the fauna is poor, be difficult to class single bottom samples with certainty among definite communities; but then more samples must be taken. Davis therefore has tried in a quantitative manner to classify the material of the sea bottom in different groups, according to the size of its particles and suggests thus to exclude his own subjective estimate, but has he thereby hit the opinion of the animals about the matter? Several of them do not ask about the size of the sand particles but about other factors, we do not know which, and they are asking about many factors. One of these, and an essential one, is persecution from carnivorous animals, another is food competition. The answer of the animals themselves, here can I live, and there I cannot, seems to me to be the fundamental fact in this matter. Experience will show how far we can get by taking "soils" as a basis for orientation among the animals of the sea bottom; the work of Davis is in its very beginning, and it is difficult for the reader to orientate himself in the results; a synoptic chart is not given. One thing, at any rate, is certain: — the Danish animal communities cannot be forced into frames determined exclusively by the nature of the soil.

However, whether it may be chosen to work in one way or another, we will surely in the course of time get valuable information on the fauna of the North Sea and, especially, on its importance as a fish food; in this respect Davis has already rendered good work. But examinations of fish stomachs must be carried out side by side with the Grab work; Davis, too, wishes this to be done in the future.

In his two papers Davis has given much valuable information on the biology of some of the bottom animals, especially with respect to the rate of growth, breeding, spatfall and mortality of *Spisula subtruncata*, a species which is of the greatest importance as a fish food in the Southern North Sea. Thus it is shown that the growth in the first year is of the order of 12—15 mm., that in the second year of 2—4 mm., and that in the third of 1—2 mm. Breeding takes place from the beginning of June to the end of September, the animals being sexually mature by the end of their first year. The mortality has been shown to be especially heavy for the 0 group, thus in one case amounting to 33 per cent. in 49 days. As to the various causes of this mortality, Davis by an examination of the dead valves comes to the result that 87 per cent. of the mortality was due to fish, 9 per cent. to Natica and only 4 per cent. to "other factors". The growth of *Mactra stultorum* was shown to be very rapid during the first months of life; Davis found an increase of 7.55 mm. in mean length in 63 days, from August till October, or an increase of 167 per cent. during this period. The mor-

tality in the same period was 70 per cent. The two above named bivalves *Spisula subtruncata* and *Mactra stultorum*, have proved to be the dominan species of the Dogger area, therefore this information about their life histor is of the greatest value.

It has been a great pleasure for me to see that quantitative botton work has now been adopted by the countries bordering the North Sea for its importance is great for the understanding of the fisheries and thei fluctuations. That the different investigators have different opinions o the principles upon which the investigations in the different seas shal be based, was to be expected beforehand. In the course of time the mos adequate principles surely will be followed during the continuation of thes investigations.

Oscar Sund. Merking av sei i Nordland Sommeren 1921. Report on Nor wegian Fishery and Marine Investigations. Vol. III. No. 5. pp. 18 Tables 4. Plates 3. English Summary. Bergen 1925.

The Norwegian Fishery Department is to be congratulated on thi large-scale marking-experiment on *Gadus virens*. Over 2000 fish wer liberated, 1000 young fish (3—5 years old) at Gildeskaal near latitud 67° N., and 1119 large fish near the Lofoten Islands.

In the four years that have elapsed since the experiment betwee 6 and 7 per cent. have been recaptured; 116 or 6 per cent. within a yea of marking, 19 or 1 per cent. in the second year, and 3 fish in the third yea This is the usual experience in marking round fish, and the reduction i the percentage of returns in the second and subsequent years remind us of the necessity of improving the technique. This is important if w are to investigate the relation of the young immature populations wit the spawning shoals. In this experiment the Norwegian "silver-coin mark was used for the small fish, and Petersen's bone and brass labe for the larger. Both types were attached to the operculum.

All Dr. Sund's recaptures were in Norwegian waters, although th experiment was widely advertised in other countries. The Lofoten an Gildeskaal fish intermingled. One of the Lofoten (large) fish went Nort as far as Tromsö, but two migrated to southern Norway. None of the sma fish migrated any long distance to Southward, but two went far to th Northward, one as far as Arnö, another to Finmarken.

Dr. Sund wisely refrains from being led by this difference into th tempting conclusion that the small fish work to the Northward and th large to the Southward. The numbers do not warrant it.

Altogether 112 out of 139 recaptures were from within 20 kilometer of the place of liberation, and Dr. Sund concludes that, in spite of th interesting cases of long-distance migrations, it is "very remarkable ho many have stayed for many months in the vicinity of the place where the were set free". Of course to find a fish after an interval even within mile of the position of liberation is not conclusive evidence that it ha remained there all the time. It has been shewn that 6 almost certainl mature cod liberated on the rocks at Flamborough Head before the spawn

ng season were recaptured within a 5 mile radius of the Head in the in-hore summer line-fishery. It seems more probable that these fish returned, n response to a "homing-instinct", after visiting the spawning-ground 30 miles away, than that they did not spawn that year. Similarly the table n Dr. Sund's paper, p. 12, would suggest that many of the large fish eturned to the Lofoten grounds each year, rather than that they emained there all the time. Thus, the recaptures within 20 kilometers n 1922 occurred from April to August but especially in May, and the pe-iods — Dec. 1921 to Mar. 1922 and Sep. 1922 to Jan. 1923 — yielded one. With regard to the smaller fish it seems likely that some have re-nained in one place while others have gradually spread Northward and Southward, for the further recaptures are on the whole later than the nearer ones.

These are the suggestions of the tables — not strictly warranted owing to the undoubted individual variation shewn, and the smallness of the numbers, and we cannot but agree with Dr. Sund in omitting these suggestions from his summary.

Exceedingly interesting is the evidence submitted on the scale-theory, vith photos of scales of the same fish on liberation and recapture. The evidence is convincing, but it is unfortunate that, owing to the difficulties of reproduction, the photos of scales from the two large fish are not clearly readable.

Perhaps the point of greatest general interest in this admirable ex-periment is one which has been observed before in marking experiments, but is liable to be forgotten, that the migrations of certain fish in certain regions at any rate, are not regular processions of individuals, responding probably to a very few stimuli, which arouse a uniformly-timed uni-directional movement — as in the migration of caribou or of swallows — but rather an exceedingly variable movement which is very difficult to sample by tracing the path of individuals. Migration of fish seems to be like the seasonal migration of *Homo sapiens* in summer, which leads the majority to the coast resorts, but a large minority, (very confusing to an investigator who might try to chart the movement by tracking indi-viduals), to the mountains, to the lakes, to foreign countries, or merely to the parks and playing fields of their own cities. That this should be so even in Norwegian waters where the possible habitat is enormously elongated and, owing to the Rinne, even scattering movements must be confined virtually to coastwise migrations in one of two directions, is certainly noteworthy.

Michael Graham.

R. Fillon. Les traitements préservateurs des filets de pêche en coton. Office scientifique et technique des pêches maritimes. Notes et mém. No. 45. Paris, Oct. 1925.

This valuable memoir merits the notice of all who are concerned with the care of fishing gear. It gives a clear and concise account of various methods of net preservation, with details concerning their application. The author emphasizes the necessity for attention to the latter if uniform

results are to be obtained. A description of the new method of treatment, involving the use of rubber latex, is included. This was devised by Dr. J. Olie of Utrecht, whose ammoniacal copper sulphate method of tanning is also given. M. Fillon has compared the latter method with that of Taylor and Wells, who use copper oleate in benzol mixed with tar. He also tried tanning (with cutch from *Acacia catechu*) followed by oleate treatment. Untreated cotton allowed to rot in sea water experienced marked deterioration from the end of the seventh month. The American method gave results above the initial value for the first eight months, but after eighteen the strength had fallen to under half the original value. Previous treatment with boiling cutch, followed by oleate with tar, resulted in the original strength being very nearly maintained for eighteen months. Dr. Olie's cutch treatment with ammoniacal copper sulphate gave somewhat superior results throughout the same period. Fillon attributes the poor results this method gave in the hands of Taylor and Wells to the fact that their own description shows that they did not carry it out properly, for they merely placed the net in the hot solution and allowed it to cool, instead of boiling for half an hour, followed by soaking for a day.

A comparison is also given of the resistance to rot of various types of cotton, treated by Olie's copper method and by that of Taylor and Wells. Egyptian Sakellaris cotton was found to be the best of those examined.

It is to be hoped that, with such cheap and easily applied methods available, the relatively inefficient methods of net preservation at present in use will soon be abandoned. W. R. G. A.

T. A. Stephenson. On a New British Sea Anemone. Journ. Marine Biol. Assoc., N. S. Vol. XIII, No. 4, Oct. 1925, pp. 880—890, with 1 Figure in the Text.

*Diadumene cincta*, n. sp. occurs on the Pier and Breakwater at Plymouth where it has been known for some time. It bears a superficial resemblance to young specimens of certain colour-varieties of *Metridium dianthus*, with which it has probably been confused. Dr. Stephenson describes the external appearance of the new species, of which there are two colour varieties, and shows how it differs from young individuals of Metridium. The internal anatomy is described by Miss E. M. Stephenson in a paper in the same number of the Journal. The new species is referred with some doubt to the little-known genus Diadumene of which *D. schilleriana*, a brackish-water anemone from India, is the type species. The affinities of the genus Diadumene and its relationship to the *Sagartia luciæ*, Verrill, are discussed. R. S.

E. Mary Stephenson. On the Anatomy and Relationships of New or Little known British Actiniaria. Journ. Marine Biol. Assoc., N. S. Vol. XIII, No. 4, Oct. 1925, pp. 891—909, with 24 Figures in the Text.

This paper deals with the internal anatomy of the following species of British Actiniaria:—

*Sagartia coccinea*, Gosse, *Metridium pallidum* (Holdsworth), young forms of *M. dianthus* (Ellis), *Diadumene cincta*, T. A. Stephenson and *Gephyropsis dohrnii* (von Koch), together with some notes on *Halcampa arenaria* (Haddon), *Sagartia viduata* (Müller) and *S. rosea* (Gosse). *Sagartia pallida* is transferred to the genus Metridium. The paper concludes with a brief consideration of the mesenteric filaments and cinclides.

R. S.

O. D. Hunt. On the Amphipod Genus Talitrus, with a description of a new species from the Scilly Isles, *T. dorrieni, n. sp.* Journ. Marine Biol. Assoc., N. S. Vol. XIII, No. 4, Oct. 1925, pp. 854—864, Plates I—III and 5 Figures in the Text.

Specimens of a terrestrial sand-hopper from the Scilly Isles, recently examined by Mr. Hunt, proved to belong to a species not yet described. It appears to be most nearly allied to *Talitrus sylvaticus*, Haswell from New South Wales. As a result of the examination of this and other material, the author defines the genus *Talitrus* in such a way as to include within it the species formerly referred to the genus *Talitriator*, Methuen. A key to the identification of all the species in the reconstituted genus *Talitrus* is given.

R. S.

Chr. Hessle. The Herrings along the Baltic coast of Sweden. Publications de Circonstance, No. 89, 1925.

The most easily distinguished character of the Baltic Herrings is their extremely small size, the main range of length being between 16—19 cm. They have also a low average number of vertebrae and the average number of keeled scales is generally lower than 14.2. The small size is due to the cold climate and very low salinity of the Baltic.

There are both autumn- and spring-spawning herrings in these waters and, according to some workers, the former are found on the coasts of Bornholm and Gotland, while the latter exist north of these places. It is probably more correct to say that both autumn and spring spawners are found along the whole coast but that the population of autumn spawners is by far the stronger, and is consequently of most importance both in the southern and northern parts of the Baltic.

The material obtained shows that the average sizes of the catches of autumn spawners decrease from North or South and also that there is an abrupt stagnation in growth in the individuals after the 3rd year. Regarding the average value of Vert. S for these herrings, it is claimed that this is greatest in the Middle Baltic and decreases from here to the North and South.

It may here be pointed out that the difference ($m$-$m_2$) between the Middle and North Baltic is .09, barely twice the standard deviation of the difference and also that the author has forsaken his own material in favour

of that of JOHANSEN, to show a difference between the Middle Baltic and the Bornholm Basin. The 791 fish of JOHANSEN represent 6 samples taken between 1887 and 1915 and in using this material the author must have assumed that in the 37 years from 1887 to 1924 the stock of fish in the Southern Baltic has remained unchanged.

The value of Vert H, in the autumn-spawning herrings is, on the whole very high, although there may be a great amount of individual variation and there are indications that this value decreases to the North and South of the Botten Sea.

On the other hand, the mean value of $K_2$ decreases regularly from South to North (14.11—13.61) and also, it is noted that this decrease may be observed in a series of samples from the North Sea to the northern part of the Gulf of Bothnia. The average size of autumn-spawning herrings also decreases from the North Sea to the Inner Baltic, as does the salinity, so there is every indication that the decrease in salinity is the principal cause of the decrease of body size and the number of keeled scales. The mean value of Vert. S may be influenced by salinity, but the variations in the Inner Baltic point to the effect of other factors than salinity. The work of Schmidt on *Zoarces viviparus* (which is not quoted) shows that in samples from Scotland and the Baltic the number of vertebrae was approximately similar in each place although the salinity in the North Sea was nearly seven times that of the Baltic, and that, in waters of the same salinity there could be considerable variation of the value of Vert. S.

The mean value of Vert. H in the autumn spawners is not governed by salinity, as this value is about the same in both the North Sea and the Baltic, but the individual variation is probably caused by local or accidental factors.

Taken as a whole, the autumn spawners of the Baltic are not divided into separate races but it is more probable that along the coast there are local groups, each one differing but little from its neighbours.

Spawning takes place along the coast or on shoals but never inside the archipelagoes, at a depth mainly between 5 and 20 metres and usually on stones or gravel. It begins in the latter part of July in the Gulf of Bothnia and continues until October in the Bornholm Basin, the period of greatest intensity being later from North to South.

After spawning there is usually a shoreward migration of the spent herrings and these movements are of great economic importance. Where the coast is very steep however, the fish stay in the same waters where they spawn, and in the winter, these herrings, along with those which had gone into the archipelagoes, descend to deeper water, where they stay until the following Summer.

From June to September the autumn herring feeds, mainly on copepods, and it is chiefly the relative amount of copepods in the different water-layers which governs the vertical movements of the herrings in these summer months.

In the North the commonest copepod is *Limnocalanus grimaldi* while further south in the Middle Baltic and Bornholm Basin *Acartia longiremis*, *Acartia bifilosa* and *Temora longicornis* constitute the chief food, and besides copepods, *Mysis* also plays a great part in the food of these herrings.

As in other areas very few of the Baltic herrings feed in winter.

Regarding the age of the autumn-spawning herrings, the 1917 and 1918 years classes formed the bulk of the catches from 1921 to 1924, but in the latter year there is evidence of a new stock appearing — the 1922 year-class. The fact that the percentages of the 1917 and 1918 year-classes was about the same in different parts of the Baltic in 1923 and 1924, suggests that the same favourable conditions for the development of the fry were present in about the same degree along the whole of the East coast of Sweden.

The catches of autumn-spawning herrings nearly always contain a number of spring spawners, usually less than 50 per cent. of the total catch. The size of these fish is less than that of the autumn spawners in the material under discussion but at the same time there are more younger fish among the spring spawners. There is a slight indication that the average size of these fish decreases from South to North but the figures quoted are not conclusive.

Regarding the racial characteristics of the spring spawners the samples were too small to draw very detailed conclusions, but the following characters have been noted: — The value of Vert. S is approximately the same as that of the autumn spawners, (or perhaps a little lower); the value of $K_2$ is very low, generally less than 13.50, and the value of Vert. H is low in comparison with that of the autumn spawners. Heincke and Johansen have also pointed out that the spring spawners usually have a lower number of keeled scales than the autumn spawners.

In the Middle and Southern Baltic spring-spawning takes place between the latter part of May and the beginning of July, on practically the same grounds as the autumn-spawning, and the movements of the spring spawners are on the whole similar to those of the autumn spawners. Living in the same shoals, it is natural that the feeding habits of these two fish are the same, and the importance of the food taken during the summer by the spring spawners is noticeable from the development of their gonads.

The two year-classes 1917 and 1918 were both strongly represented in the catches but unlike the autumn spawners, the 1920 year-class was also present.

This seems to show that in 1920, the favourable conditions for the development of the eggs and larvae only lasted for a short period and so differentiated between the products of the spring- and autumn-spawnings of that year.

Inside the archipelagoes and fjords of the Middle Baltic is a fishery which lasts during the whole year. It is dependent on stationary local races called by the author "Fjord Herrings". These, he says, are quite distinct from the "Sea Herrings" mentioned above, for they live in waters which are never entered by the latter herrings. In size they vary considerable, both small fat herring and very large individuals being often caught in the same haul.

Their rate of growth may vary very much even in two neighbouring fjords, and to illustrate this it may be mentioned that, while in one fjord, normal herrings occur, ripe fish of 10 cm can be found in an adjacent fjord. Contrasted with the Sea Herrings the sudden stagnation of growth is more

or less absent in these herrings and the increase from year to year is more even.

The values of $K_2$, Vert. S and Vert. H, are very low, and that there are different local races, is shown by the difference in $K_2$ between three samples, from Vaxholm, Gamlebyviken and Stora Rör. The numbers of fish used to show this difference are much smaller than the sample which was discarded by the author as being inadequate, when he dealt with the value Vert. S, for the autumn-spawning Sea Herring.

The Fjord Herrings spawn from April to the end of the summer, and mainly in June, so they may be more correctly referred to the spring-spawning groups.

The very large herrings which appear in the fjords are never found in the Inner Baltic and, according to HEINCKE, have not migrated to the fjords from waters west of the peninsula. An examination of 50 individuals has shown that they are in close agreement with the Fjord Herrings.

The catches of the Fjord Herrings contained a high percentage of one and two year old fish but unlike the spring and autumn spawners the 1917 and 1918 year-classes were not well represented.

In the Gulf of Bothnia, as soon as the ice has broken up in the spring, another fishery takes place, and this is dependent on spring-spawning herrings locally called "Ice Herrings".

Here again, they are mainly very large fish and, from their scales, seem to have a rapid growth, and they spawn chiefly in June.

It is possible that in these herrings also, the 1917 and 1918 year-classes were well represented. The characteristics of these Ice Herrings are different in many respects from both the Fjord Herrings and the spring-spawning Sea Herrings but there seems to be such a mixture of characters typical of one or the other, that it is possible that "Nature has tried to amalgamate two races into one."

The problem of "races" among fish — herrings perhaps, in particular — has always been a most intriguing one, and one feels justified, while dealing with this most interesting account of the Baltic Herrings, in bringing to light some of the points which are not altogether clear to an investigator whose own results make him antagonistic to the "race" theory in all but the broadest sense.

The main difficulty is in the arbitrary method of sorting a sample of fish into autumn and spring spawners. These occur together in the same shoal — the spring fish spawning from May—July, and the autumn fish from July—October, and also there are ripe spring spawners in the catches of October.

In tables 20 A and 20 B for instance, the sample of May 22, 1924 from Hanöbukten is divided into two groups according to maturity.

Stages II and III are called autumn spawners and IV and V spring spawners, and as the result of such a division, characters are compared, but the differences shown are small.

The spawning seasons overlap and cross fertilization seems inevitable, especially as the males of the "autumn spawners" are probably in an advanced stage of maturity compared with the females, so a mixing of characters would be a natural result.

In figs. 2 and 3 are shown typical scales from autumn and spring spawners. One has a larger $l_1$ than the other, and if fish bearing such scales are found at the same stage of maturity in a ripe shoal, then the question of the occurence of "races" must be examined with caution. In other words, do herrings which are spawned in the spring invariably spawn in the spring?

May not a study of environment and its consequent effect on growth (as shown by the scales) be more helpful in the solution of herring problems? Time alone will tell!

W. C. Hodgson.

William C. Hodgson. Investigations into the Age, Length and Maturity of the Herring of the Southern North Sea. Part II. The Composition of the Catches in 1922—24. Fishery Investigations. Ser. II. Vol. VIII No. 5. 1925.

This paper presents results of investigations regarding distribution and lengths of young immature herrings of the I-Gr and II-Gr and regarding length, age and maturity of older herrings taken in the southern and western part of the North Sea in 1923 and 1924. The material of immature herring was mostly procured by the English research vessel "George Bligh", and it was the object of Mr. Hodgson by a constant sampling of these younger year classes to learn something definite concerning their distribution and origin.

As regards herring of the I-Gr Mr. Hodgson has been able to show that they occur in great quantities in the open sea, especially in the region of the Dogger Bank. The bulk of the young herrings met with in this area were those which had been approximately 8 cm at the end of their first growth period and which — according to Mr. Hodgson — were spawned in the late autumn and winter in the Southern Bight of the North Sea. In a series of hauls on the Tail End of the Dogger Bank it was found that the lengths of the herrings of the I-Gr increased with the depths, the modal length of the specimens taken at 36 fms depth being about 2 cm longer than the length of those taken at 22 fms.

Whilst Savage in 1914 in the Thames and the Wash found herrings of the I-Gr which were approximately 10 cm long at the end of their first year, no trace of this type of the I-Gr was found by Hodgson in 1923 and 1924, and he concludes that this group normally exists in waters other than the south-western North Sea.

The II-Gr of the Herring are caught each summer off the Northumberland Coast. These are mostly immature fish, but some of them become mature for the first time in these waters. Both in 1923 and 1924 mature herrings with three zones on their scales occurred in these waters, but the commonest mature fish were those with 4 zones on their scales. Comparing the types of the "three"s and "four"s for each year Hodgson found, in 1923, the former to be "the winter spawned type" (8.6 cm at the end of their first year) and the latter "the later summer-autumn spawned" (10.3 cm at the end of their first year).

In 1924, the four zoned herring were found to have the same characteristic length, as the "three"s of the previous year, suggesting a return to the spawning shoals of the latter fish.

Herrings with four growth zones on their scales were also abundant in the Southern Bight, but these were accompanied by many more older fish than in the more northern area off the English Coast.

In the eastern part of the Channel it was found that the four-zoned fish of 1923 were replaced by five-zoned fish in 1924 and each of these had approximately the same large centre zone (12.34 cm and 12.91 cm).

Hodgson gives some new important information about the spawning time of the herrings in the Southern Bight, and supplements hereby the very valuable records given by William Wallace in 1924. It was found that there are definite spawning grounds in the Smith's Knoll area in October, November and December and in the Gabbards-Sandettie area in November—December. The spawning in the last named area is, according to Hodgson, of great importance, and probably unequalled in intensity in any other part of the North Sea.

The "Annual Ring Theory" is, no doubt, a valuable guide in the determination of the age of the herring, but the method is by no means an exact one, and the present recorder thinks it probable that very many mistakes are made in the actual reading of the age, even by experienced investigators. When Hodgson calculates that the average length of the Channel Herring at the end of their first year is between 12 and 13 cm, it would seem natural to ask if this size is not that reached at the end of the second year. The young herrings which occur in great numbers off the west coast of Jutland and have their origin from late summer or autumn spawners, have an average length of 10 cm at the end of their first growth period, which lasts about 12 months. Wallace has shown that the Whitebait Herring of the south-eastern English coast, which probably are hatched mostly in the months of November and December, usually have an average length of 8 cm at the end of their first growth period, which lasts about 10 months. It would seem improbable, therefore, that herrings from the Channel, which are hatched in the winter or early spring, should reach a length of 12—13 cm in the course of a single growth period, which does not last longer than about 8 months. New investigations on this point seem to be needed.

Wallace has shown that a great part of the "Lowestoft-Yarmouth Herrings" are spawning in the Southern Bight in October, November and December, and that there is no lull between the spawning in this area and the spawning in the area between Northumberland and Cromer, including the Dogger Bank. Hodgson adds new evidence in the same direction and maintains that the actual spawning time in the Southern Bight is variable. These facts point in the direction that many more of the "Lowestoft-Yarmouth Herrings" belong to the same race as the Dogger Bank Herring than the present reviewer had expected. But Hodgson goes too far when he maintains that all winter-spawning herrings occurring in the Southern Bight belong to the same race as the Dogger Bank Herring. Redeke has investigated two samples of herrings taken in the area $G_4$ of the Southern Bight and has found that they deviate distinctly from the Dogger Bank

Herring and agree with the winter spawning herring of the eastern part of the Channel. The samples were taken in November 1905 and the stage of maturity was for one of them III-V and for the other IV-V. Thus there is no doubt that the samples belonged to a winter spawning herring. Each of the samples consisted of 100 specimens, and in one of them the average number of keeled scales ($K_2$) was 14.16 $\pm$ 0.065, in the other 14.38 $\pm$ 0.065, while the herrings spawning between Northumberland and Cromer — including the Dogger — in the months July—November have 14.80—15.00 keeled scales in mean value. These results obtained by Redeke are by no means invalidated by the recent investigations of Wallace and Hodgson. Whether the spawning places for the herring-race found by Redeke in the Southern Bight are situated exclusively in the eastern part of the English Channel or whether they also occur in the Southern Bight, is an open question. This herring-race is undoubtedly spawning in water of a lower temperature than the herrings of the Dogger Bank type. A very great decrease in the temperature takes place in the Southern Bight during the last months of the year. In the middle of October the mean temperature of the water is ca 14° C., in the beginning of November 11—13° C., in the beginning of December ca. 9° C., and at the end of December ca. 8° C. A statistical investigation as to the number of vertebrae, fin rays and keeled scales in the herrings spawning there will be a guidance which the English investigators cannot dispense with.

A. C. Johansen.

B. Sæmundsson. Age and Growth of Haddock (*Gadus aeglefinus L.*) and Whiting (*Gadus merlangus L.*) in Icelandic waters. Meddelelser fra Komm. f. Havundersøgelser. Serie Fiskeri, Bd. VIII, No. 1, 1925.

Having completed another stage in the study of much admirably collected material Bjarni Sæmundsson (Director of the State Museum at Rejkjavik, Iceland) has, as a sequel to his paper on the Cod (i), published his results on Haddock and Whiting. The latter, a rather unimportant fish to the Icelander but of some significance to the foreign trawler, might preferably have been grouped with the Cod, which it resembles in behaviour rather more than does the Haddock. The author points out that prior to his first reports to the Icelandic Government (ii) no investigations had directly been focussed upon Icelandic Haddock, which merits study from its importance not only as the favourite fish diet of the islanders but since it takes third place to Cod and Herring in the Icelandic export trade. From the economic as well as the biological outlook the powers of sustained productivity (chiefly on account of the rapidity of growth of the round fish) of the Iceland grounds merit the far more intense study coming to be bestowed upon them.

The author, practically singlehanded, has spared no effort to collect and interpret a set of material — consisting of the lengths, maturities, weights and scales of the fish — which is representative, but necessarily rather scanty for a final treatment of the subjects. No one has a better first hand knowledge of the incidence and course of the two ruling cur-

rents — the warmer Atlantic Stream towards the South-West of Iceland, and the colder Irminger current towards the North-East. Perhaps the five regions into which he subdivides the coast will ultimately be reduced to two, bounded by the points he himself selects — Straumnes and Eystra Horn.

In the age-reading of Haddock scales Sæmundsson has found little difficulty save among older fish, where at first confirmation was obtained from the clear zoning of the thick breast bones, which he suggests are probably adaptations to the Haddock's preference for life near the sea-floor, weighing down the fore part of the body in the search for food. Owing to the rapid burst of growth in June there is a clear line of demarcation between winter and summer growth on the scale. Slight difficulties may arise in scales from old fish owing to less distinct differentiation and the congestion of the annual rings. The rate of growth for Haddock was found to be uniformly fast on the south and west coasts, but to become slower on the north coast, and still slower on the East. The spawning grounds lie on the south and west coasts, and the fry may be distributed there in deep water (80 metres) or drift varying distances round the coast clockwise, in some years reaching as far as the East side. Growth then proceeds at a rate varying with locality until maturity, when there is a return migration to the spawning grounds, and such intermixture that when the summer and autumn feeding grounds are again sought out it is impossible to say that one region contains fish of markedly different growth rate from another. The author thinks that first maturity is not generally reached till 4 years of age, and even 6 years is instanced in extreme cases. This appears rather late an age for Haddock to spawn for the first time, and most of the observations were made in July—August, when there is frequently difficulty in telling a recovering spent from a virgin fish. Female fish grow somewhat larger and older than male. The fishing season lasts all the year round on the south and west coasts, reaching greatest intensity at the spawning season; whereas in the North and East there is only a summer and autumn season of 5—6 months. Large Haddock seldom approach the sandy shallows except when recuperating after spawning, when the sand-eels of the bights form the chief food. Among the 1700 scales examined ages up to 14 years were recorded, the largest representing a fish of 104 centimetres in length. After 6—8 years growth becomes very slow, as does the annual increase in weight. This is an important point from the economic standpoint, as is also that, mentioned by the author, that for a month or two after spawning the haddock are so lean as to be almost inedible. Although the bulk of the Haddock caught are immature there is no prima facie evidence from the Icelandic statistics that the stock is being badly deplenished.

Whiting are shown to attain a maximum size of 68 cm, fully one-third greater than in the North Sea. The annual rings are not so well defined in the scales as in Haddock, and among the 250 samples examined few exceeded 6 years of age. Most of the Whiting occur on the south-west coast in deep water (80—100 metres), so that there is no opportunity of applying the regional test to growth rate. Female fish are markedly larger than male, and appear to live longer. Maturity is reached at as early an

age as 2 years, but the majority remain virgin fish until the third year. The annual crop of fry and young fish is very variable. As in the case of Haddock, signs of depletion of the Icelandic stock of Whiting are not evidenced by the local statistics.

H. Thompson.

(i) Meddelelser f. Kom. f. Havundersøgelser. Ser. Fiskeri. Bd. VII, No. 3, (1923).
(ii) Fiskirannsóknir, 1915—16, Andvari XLII, p. 97—108.
— 1917—18, — XLIV. p. 68—75.
— 1919—20, — XLVI, p. 64—69.

O. Sund. — Nyt Fiskertermometer *(New Fishery Thermometer)*. Fiskets Gang, 10th Feb., 1926, pp. 60—1.

Mr. Sund describes and figures a simple reversing thermometer adapted for use by fishermen. It can be worked on a thin line, and the reversing mechanism is operated by a messenger. This appears likely to be of great practical service to fishermen in Norwegian waters, and also elsewhere, e. g. in the Barentz Sea and round Iceland. »As an example of what has already been accomplished by the use of the thermometer we need only mention that the large mature cod at Lofoten are practically always found (where investigations have been made) when the temperature is between $4^1/_2$ and $6^1/_2$ degrees. When the bottom temperature was found to be over $6^1/_2$ degrees (in the West Fjord in winter the temperature increases with the depth) the fish were found to be in lesser depths, so that it was necessary for the gear to be set at some distance from the bottom«. »In southern Norway too, where large coal fish occur in winter, guidance can also be obtained by the use of this thermometer in seeking that variety of fish. Large coal fish are rarely to be found in temperatures below 6°«.

The fishery thermometer is supplied complete, with a guarantee, by the firm Bergen Nautik, Stølegaten, Bergen, at the price of 100 kr.

E. S. R.

S. W. Averinzev. (Institute of Fisheries, Moscow.) Results of Hydrological Work conducted in the Region of Cape Kanin (Barentz Sea) in connection with Fisheries. Annals & Magazine of Natural History, Vol. XVII, pp. 117—126. January, 1926.

In his paper Dr. Averinzev records the results of the fishery investigations which he undertook in the year 1918. He is to be congratulated on the successful organization by which he was enabled to carry on his observations side by side with commercial fishing in such a way that the cost of the expedition was covered by the value of the catches. To work under such conditions necessarily placed limitations on the research, but there was the compensatory advantage that the commercial application

of the work was held constantly in view. It is to be regretted that circumstances prohibited the continuation of the work in the following year.

A steam trawler was hired and three voyages were made between the 28th August and the 17th November, during which an area of some 7,000 sq. miles adjacent to Cape Kanin was covered. The depth of water in this area was between 20 and 50 fathoms.

The main result of the work is further to impress on the fisherman in these regions the necessity for using a deep sea thermometer.

On the first voyage (28/VIII—14/IX[1]) a sharply defined water-mass, covering approximately 30 sq. miles was encountered on the bottom a short distance N.W. from Cape Kanin. The temperature of this water-mass was high ($> 4°$ C.) and the salinity low ($32‰$) in relation to the temperature ($< 1°$ C.) and salinity ($34‰$) of the surrounding bottom waters, and on this account the presence of this warmer, fresher water was attributed to an outflow which had occurred from the White Sea along the Kanin Peninsula. It may be recalled that only towards the end (July 1913) of the "Poseidon" expedition to the Barentz Sea was the water streaming out from the White Sea found to be warmer than the water of the open sea.

An hour's fishing in the warmer water yielded from 1,000 to 1,600 kilograms of fish, and even, at times, as much as 3,500 to 4,500 kilograms: approximately a quarter of the catches consisted of cod and the remainder was nearly all haddock. Beyond the warm water region the yield fell sharply to between 40 and 400 kilograms per hour, the proportion of cod to haddock in the catches increasing with falling temperature. From this and from the "Poseidon" results it may be gathered that the haddock do not begin to come into the Kanin area in abundance until the water temperature has risen above 2° C., for cod far outnumbered haddock in the catches of the "Poseidon" expedition on which the temperature of the bottom water was, with few exceptions, below 2° C.

While entirely barren regions were nowhere found, fishing in the colder districts is to be regarded as unprofitable. Variations within the different regions are attributable to the shoaling of the fish. Though it is stated that fluctuations of temperature between 0° and 2° C. had no effect on the results of the fishing, this condition is probably to be regarded as having only a local significance, since the "Poseidon" catches, the great majority of which were made in water below 2° C., though over a wider field, varied considerably from place to place.

As regards the condition of the fish from the point of view of nourishment, no difference was observed between fish from colder and warmer districts.

At the beginning (29/IX—6/X) of the second voyage (28/IX—16/X) the warm water-mass had become dispersed with the consequent extension of more or less uniform conditions of temperature and salinity to a larger area. The quantity of fish caught increased generally and the catches were more evenly distributed. Towards the end of this voyage (9/X—16/X) a fresh region of high temperature and low salinity had become established, as before, on the bottom off Cape Kanin. Though the bigger catches still

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[1]) given as 14/X in the text. In Fig. 1, two stations are dated 29/IX.

tended to coincide with the higher temperatures the sharp distinction between fishing grounds found earlier was not observable.

By the third[1]) voyage (3 XI -17 XI) dispersal of this second warmer water-mass had taken place. The proportion of cod to haddock in the catches had increased to such an extent that in some places more cod were caught than haddock. Though none of the catches were remarkably large, they were nevertheless sufficiently large to make the trawling profitable, the concentration of fish over the area as a whole having apparently increased since the time of the first voyage.

A number of slips have occurred which in certain cases render the paper a little difficult to follow. To take two of the more unfortunate examples, the numbering of the figures appears to require adjustment:

For Chart headed "Fig. 2" read "Fig. 4"
" — "Fig. 3" — "Fig. 2"
" — "Fig. 4" — "Fig. 3"

And the salinity numbers throughout are given "per cent." where surely "per mille" is intended.

J. R. L.

Heincke, F. & Bückmann, A. Die Ueberfischung der Nordsee und die Wirkungen der Kriegsschonzeit auf ihren Schollenbestand. Der Fischerbote. Norddeutsche Fischerei-Zeitung. XVIII. Jahrg. Heft 3. 1. Februar. 1926.

This article is a most valuable contribution to our knowledge of the plaice fisheries just off the German coast. Its object is to show the effect of fishing and in particular over-fishing on the plaice stock of the North Sea. With this in mind the paper should be read in conjunction with other recent reports which treat of the North Sea as a whole, since the German investigations, with the exception given below, treat only of the very numerous measurements and age-determinations made in an area of 10 sea miles round Helgoland. This work has been carried out with great thoroughness and the results analysed with the utmost clarity giving in all probability a very true picture of the changes in size-distribution and the growth of the plaice in the area examined during five periods dealt with: —

1. Before the war when the area was over-fished and the growth of the plaice was rapid.
2. During the war when little fishing was carried on, the stock of plaice was accumulating. (These investigations, however, inevitably were carried out on a very small scale and cannot be considered as reliable as the rest).
3. Immediately after the war when the fishing had been resumed, the stock particularly of the older plaice was still very dense and the growth rate lower than during the war.

[1]) the fourth voyage in the text.

4. In 1922 when the accumulations had been fished out but the effect of the war protection was still evident in the presence of large broods of young fish — the progeny of numerous mature plaice that were present in the North Sea immediately after the war. The growth rate during this period was still lower than before.
5. In 1925 when the stock showed signs of a speedy return to the condition of pre-war years both in size-composition and rate of growth.

It is much to be regretted — and this is evidently strongly felt by the Authors themselves — that the investigations did not render it possible to make any exact estimations of the density of the stock as a whole and more particularly of the age-groups. The former is deduced to some extent from the catch per hour of a 90 foot Otter Trawl on five fishing grounds — three in the close vicinity of Helgoland, one off Juist and one on the Sylt Inner Ground during July and September in various pre- and post-war years. These catches, however, are not analysed for size distribution nor for age determinations, and beyond showing that the number and weight of plaice caught after the war, even up to 1925 was greater than before it, do not give much information. A greater or lesser density is, however, correlated by the authors with changes in the growth rate of the fish. Thus a slow growth presupposes a very large population and vice versa. The low rate of growth, quite properly, is believed to be due to the food present being insufficient to enable a great number of fish to grow rapidly. But that this lack of food is due entirely, as the writers suggest, to the great density of plaice alone does not appear to the reviewer to be as simple an explanation as is supposed. Surely it is possible that there are other factors? Is it not possible that at the same time there was a great density of other competitors for the same food such as haddock and dabs, and again that the food supply itself may fluctuate in abundance as Mr. Davis has shown to be the case with certain molluscs on the Dogger Bank?

The growth determinations made from marked plaice in the old statistical Area $A_3$ by Dr. Johansen from 1906 to 1912 when the Area was well fished show that the variations in the rate of growth from year to year are quite as considerable as those given in this article from pre- and post-war periods; moreover they bore no relation to the greater or lesser density of plaice as evidenced by the fluctuations of the catch per day's absence by British Steam Trawlers in the same area during those years.

The reviewer, however, does not intend to dispute the assertion that a very great density of plaice affects the growth rate, which has indeed been well proved in the case of the Limfjord, but merely to suggest that it may not be the only cause.

The final summing up of the present conditions of the plaice fishery and of the necessity for protection are in complete agreement with the views of the representatives of the various countries who have been working on the problem of the preservation of the supply of plaice during recent years.

D. E. T-P.

# A Selected Bibliography of Marine Bionomics and Fishery Investigation.

Compiled by

**E. J. Allen.**

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# PART II.

## Fishes and Fishery Investigations.

### Fishes.

GENERAL


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